Sludge Utilization and Disposal

Conference Proceedings No. 6

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PROCEEDINGS

SLUDGE UTILIZATION AND DISPOSAL SEMINAR

Toronto, Ontario
February 20 and 21, 1978

CANADA-ONTARIO AGREEMENT ON
GREAT LAKES WATER QUALITY

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FOREWORD

The Government of Canada and the Government of the Province of Ontario signed an agreement on August 13, 1971, to ensure that the water quality of the Great Lakes is restored and protected. One of the principal provisions of the Canada-Ontario Agreement was to provide for the acceleration of the construction of municipal sewage treatment projects for the abatement of pollution and to introduce phosphorus removal at all significant municipal sources. An additional important financial provision of the Agreement was for a research program directed towards reducing the cost of waste treatment and ensuring that the latest technological advances were incorporated to achieve the specific water quality objectives set out in the Agreement. A significant concern which was identified was the handling and disposal of sludges produced from the chemical treatment of sewage for phosphorus removal. Under the direction of the Subcommittee for the Land Disposal of Sludges, research projects have been conducted, both in-house and through external contracts, on sludge handling and disposal methods.

A seminar was held in Toronto in 1974 which presented the results of the sludge handling and disposal research conducted up to that time*. The seminar held in Toronto on February 20-21, 1978, updated the 1974 seminar by highlighting the results of six years of research activities on sludge management. Fifteen papers were presented, covering all facets of sludge handling from sampling methods and metal sources, through sludge conditioning and dewatering to incineration, composting and the regulatory aspects of sludge disposal.

Sludge handling and disposal is the most difficult and most costly single aspect of wastewater treatment today. Up to 60 percent of the total cost of operating and maintaining municipal wastewater treatment plants is associated with sludge management. Cost-effective sludge disposal requires the examination of all process options. The papers contained in these proceedings should serve as a useful reference to municipal engineers and administrators, consultants, regulatory agencies, pollution control plant personnel, health officials, agricultural scientists, engineers, and equipment manufacturers.

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AVANT-PROPOS

Le gouvernement du Canada et la province de l'Ontario ont signé, le 13 août 1971, un accord destiné à assurer le rétablissement et la protection de la qualité de l'eau des Grands lacs. L'une des principales dispositions de cet accord prévoit la construction accélérée d'installations municipales d'épuration, la mise en oeuvre de projets d'assainissement et le retrait du phosphore de toutes les sources urbaines importantes. L'accord prévoit, en outre, l'attribution de sommes d'argent pour un programme de recherche destiné à réduire le coût de traitement des déchets et à assurer l'utilisation de techniques de pointe pour atteindre les objectifs spécifiques de qualité dudit accord. On a ainsi considéré importante la manutention et l'évacuation des boues d'épuration chimique pour en retirer le phosphore. Sous la direction du sous-comité sur l'épandage des boues, les services gouvernementaux ont effectué, eux-même ou par l'intermédiaire de contractants, des recherches sur la manutention et l'évacuation des boues.

Le colloque tenu à Toronto en 1974 présentait les résultats des recherches menées jusqu'alors dans ce domaine.* Les 20 et 21 février 1978, avait lieu à Toronto un second colloque qui mettait à jour les données fournies lors du précédent en exposant les résultats de six ans de recherche sur la gestion des boues. On y a présenté quinze documents portant sur tous les aspects de la manutention des boues, depuis les méthodes d'échantillonnage et d'identification des sources de métaux, jusqu'au traitement, à la déshydratation et à l'incinération des boues, en passant par la fabrication de compost et la réglementation de l'évacuation des boues.

La manutention et l'évacuation des boues représentent actuellement les aspects les plus difficiles et les plus coûteux de l'épuration. La gestion des boues absorbe jusqu'à 60 p. 100 du budget total d'exploitation et d'entretien des installations municipales d'épuration. Pour en arriver à une évacuation efficace et peu coûteuse, il faut examiner tout l'éventail des procédés connus. Les communications présentées dans ces comptes-rendus devraient se révéler utiles aux ingénieurs et administrateurs municipaux, aux conseillers techniques, aux organismes de réglementation, au personnel des installations de traitement, aux responsables du secteur de la santé, aux scientifiques spécialisés en agriculture, aux ingénieurs et aux fabricants d'équipement.

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PRACTICES AND TRENDS IN SEWAGE SLUDGE UTILIZATION AND DISPOSAL

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INTRODUCTION

Sludge handling and disposal is the single most costly phase of municipal wastewater treatment. Although the sludge produced in the sewage treatment process is only about 0.5% of the total liquid volume treated, sludge disposal costs usually represent between 30 and 50% of the total costs associated with the complete wastewater treatment process.

Sewage treatment has traditionally been designed to optimize effluent quality and, until recently, much too little emphasis was placed on sludge handling and disposal. Sludge management must receive at least an equal effort in planning as does the actual sewage treatment process.

Sludge management options are numerous and diverse and the choice of system for a particular project is influenced by a multitude of conditions and factors. If we are serious about cost-effective sludge disposal, however, all available unit processes must be considered. Solutions must be developed that are acceptable not only from a cost standpoint but from an environmental and public health and acceptance viewpoint as well. The rewards for a comprehensive assessment can be considerable, not only in direct cost savings but also by the adoption of a system in accord with environmental concerns and public demands.

This paper presents a brief assessment of the various reuse and disposal options for ultimate sludge disposal and relates treatment requirements to specific disposal options. As the entire program of this seminar is directed towards sludge treatment and disposal, each of these areas will be dealt with in detail in subsequent papers during this seminar. This paper provides an overview only of various options available.

The paper then reviews current sludge management practices in other countries, looks at the quantity and quality of sludge produced in Ontario and discusses various factors affecting its production. The paper concludes by predicting future trends for sludge treatment and disposal in Ontario.

SLUDGE MANAGEMENT CONSIDERATIONS

There are several factors which must be kept in mind when planning a sludge management system. For all situations, other than some options involving resource recovery, sludges in one form or another must be disposed of in the environment. The air environment is not a suitable sink for the majority of sludge constituents and controls on emission of materials into the air are becoming more and more restrictive. Fresh water can also be eliminated from consideration as a receptacle for sludge. Current policies discourage practices such as ocean dumping of sludge as long term solutions. Thus, sludge in some form will eventually be returned to the land.

The first step in setting up a sludge management system should be the selection of the ultimate disposal option to be used, giving adequate consideration to projected sludge quality, quantity and environmental and public concerns of the specific project area. The next step then would logically relate to the processing requirements best suited to the disposal option selected.

Sludge management evaluations should include due consideration to reuse and recovery alternatives. No matter what ultimate disposal option is selected, there is always a significant cost associated with sludge processing and disposal. Revenues from byproducts of sludge can recover portions of those processing costs.

Additionally, the sludge management planner must carefully consider the compatibility of various processes. For example, the effect of heat treatment liquor on the plant biological processes must be considered before selecting such a sludge conditioning process.

Regionalization of several smaller wastewater systems into a larger system may favourably affect the relative economics of some sludge disposal alternatives to the degree that they then become economically and environmentally attractive. Heat drying of sludge for use as a

fertilizer, for example, decreases in cost by a factor of nearly 2 as plant capacity increases from 10 mgd to 50 mgd, while the cost of anaerobic digestion decreases by only about 10% [1].

In some cases, integration of solid waste and wastewater sludge disposal plans may offer a useful, synergistic relationship. For a given population, the volume of solid wastes is about 10 times that of wastewater sludge. Thus, inclusion of sludge with solid waste may not significantly alter the volume of material to be handled in the solid waste system.

One must have a very basic understanding of the individual unit processes available as well as the environmental constraints applicable to location and plant conditions in order to properly formulate sludge management plans.

ULTIMATE DISPOSAL OPTIONS

Although a large number of alternative combinations of equipment and processes are used for processing sludge, the basic alternatives for ultimate disposal are fairly limited. The ultimate depository of sludge must be the land.

There are two basically different approaches in the handling and processing of sewage sludge. One is directed towards reuse, the other towards disposal. The reuse approach is based upon recycling sludge so that nutrients, organics and/or other materials contained in the sludge are beneficially reused. The goal of sludge treatment in this case is to make the sludge compatible with the proposed reuse system. If land utilization is being considered for ultimate disposal for example, prior treatment should be such as to conserve its nutrient value and organic matter content and to make it aesthetically acceptable.

The organic solids which make up 60-80 percent of the solids in a typical municipal sludge are also a potential source of energy. Some treatment processes convert these solids so that this energy can be beneficially reused. Again, any prior treatment should conserve the organic fraction of the sludge.

The disposal philosophy considers the sludge as a waste material and therefore such systems generally incorporate treatment techniques to provide for maximum reductions in the volume of sludge to be disposed.

The choice between reuse and disposal approaches must be based upon a thorough evaluation of many factors associated with each of the processes involved. In the current age of resource depletion and energy shortages, however, reuse and resource recovery should receive a priority if either can be feasibly included in the sludge management scheme.

Reuse Techniques

As mentioned above, sewage sludges contain nutrients and organic solids which have a potential value for reuse options. The primary reuse technique universally applied is utilization on agricultural lands. Other options include the recovery of the calorific values of the organic matter contained in the sludge through energy recovery processes, the recovery of valuable materials contained in the sludge, product development and wasteland reclamation. Each of these options are briefly discussed below.

Utilization on agricultural land

Land utilization is an attractive alternative for ultimate disposal of sewage sludge because of the minimum amount of prior processing required and the potential for reuse.

The use of sewage sludge in agriculture is based upon its nutrient content for plant fertilization and its organic matter content for soil structure improvement. As a fertilizer, sewage sludge contains all of the elements essential to plant growth. A typical sludge contains about 4% nitrogen, 2.5% phosphorus and 0.5% potassium on a dry weight basis. At current (December, 1977) fertilizer prices of 20¢/lb nitrogen, 36¢/lb phosphorus and 10.3¢/lb potassium, one ton of sludge has a fertilizing value of about $16.04* in addition to its value as a soil amendment.

The application of sludge to agricultural land poses a number of potential environmental hazards, however. Sludges contain varying concentrations of heavy metals. Metals in sludge which are potentially hazardous to plants or the food chain are B, Cd, Co, Cr, Cu, Hg, Ni, Pb and Zn. Heavy metal levels within a particular sludge may limit its acceptability

* This value assumes that 40% of the nitrogen, 50% of the phosphorus [2] (a conservative estimate), and 100% of the potassium is available.

for land utilization. Therefore, every effort should be made to limit the discharge of metals to the municipal sewer system through industrial waste pretreatment if land application is to be considered.

Sludge constituents such as viruses, organics, pathogens and parasites are of concern from the standpoint of their ultimate fate and effect on the environment. Adequate treatment of sludge, such as anaerobic digestion, prior to land application is required for stabilization of the organic matter to reduce its odour potential and for reduction in pathogenic organism content.

The amount of nitrogen contained in the sludge is of concern because of the potential for nitrogen to leach to the groundwater in the form of nitrates. To avoid this, a balance between nitrogen applied in the sludge and that removed by the crop must be reached.

Sludge may be applied to agricultural land as a liquid or in a partially dewatered state. Since any dewatering process considerably increases the cost and complexity of a sludge management system, liquid haulage is preferred unless haulage distances become too great. It should be kept in mind that almost one-half of the nitrogen in digested sludge is in the liquid fraction; therefore, thickening and dewatering will reduce the nitrogen level significantly.

Product development

Sewage sludge may be processed to produce a stable end product which can be sold and distributed as a fertilizer and/or soil amendment. Composting and heat drying are really stabilization processes but are included in this assessment as ultimate disposal techniques because they produce a unique material specifically produced for reuse and for sale to recover some of the processing expenditures.

The major marketing potential for compost and dried sludge utilization is for specialty crops, home gardening, golf courses, etc.

a) Composting. Composting is a method of biological oxidation of organic matter in sludge by thermophilic organisms. Composting, when properly carried out, will dewater, destroy objectionable odour-producing

elements of sludge, destroy or reduce pathogenic organisms because of high temperatures, and produce an aesthetic and useful organic product.

The compost product has a slight musty odour, is moist, dark in colour but can be bagged and stored. Its texture varies depending upon degree of screening. Compost is valuable as a soil conditioner and low grade fertilizer but varies widely in composition, although typical compost contains an average of about 1.5% nitrogen and 1.0% phosphorus.

Some of the problems associated with sludge composting are the effects of adverse weather conditions such as cold or rain in non-enclosed areas, potential production of odours, and the slow rate of composting for waste activated and chemical sludges.

b) Heat Drying. Sewage sludge may also be heat dried for production as a fertilizer and soil amendment. Drying, however, results in a product low in nitrogen and nitrogen supplementation is required for the product to be sold as a fertilizer. Although several cities, including Houston, Texas and Milwaukee, Wisconsin, still practice sludge drying and fertilizer production, many drying installations have been abandoned. This is because of inherent high costs of operation (typically twice or more the cost for incineration), inherent odour problems, air pollution and explosion potential due to the fine particulates, and the fluctuating demand for the dried product.

Land reclamation

Sewage sludge has been used to reclaim strip-mine spoils or other low-quality land with considerable success. As high application rates (40-400 tons/acre/year) are commonly used, the potential for water contamination, if drainage and runoff controls are not installed, is great. In addition, the large amounts of sewage sludge required to reclaim land may cause excessive accumulation of trace elements in soils. Depending upon the anticipated future use of the reclaimed land, controls on heavy metal contents of the sludge may well have to be also applied for this reuse alternative.

Energy/resource recovery

Energy and resource recovery processes are attractive because they are not only effective in sludge disposal, but are also designed to recover a valuable resource at the same time. Because of the projected resource shortages, this conservation approach to sludge disposal will undoubtedly intensify in the future.

Some examples of this approach are: 1) recovery and recycling of marketable constituents of sludge or sludge incinerator ash, 2) co-incineration of sludge with combustible solid waste to generate power or steam, or 3) pyrolysis of sludge to produce useful byproducts such as fuel gases, oils, tars or activated charcoal.

Because of its relatively high calorific value, sewage sludge has the potential as a low grade fuel for use in energy recovery schemes. Although the calorific value of sludge varies considerably, it is influenced primarily by the volatile solids concentration of the sludge and the nature of those solids. A typical sludge has a calorific value of between 5,000 to 6,000 BTU/lb dry solids but a recent study [3] of eight Ontario sludges showed a range of from 1,770 to 7,130 BTU/lb dry solids; the lower value being for a primary lime sludge and the higher for a heat conditioned sludge.

Pyrolysis is a heating process whereby sludge solids are subjected, in the absence of oxygen, to temperatures of from 900 to 1,700°F and produces gases, oils and tars as well as large quantites of water vapour, each with a potential for energy recovery.

Sewage sludges contain a diverse number of heavy metals and in some sludges the concentration of one or more can be very high indeed. Although the emphasis should be put on keeping high levels of metals out of municipal wastewater, some sewage sludges present the potential for economic recovery of metals.

Recently, precious metals worth more than $200 per metric ton were found in the Palo Alto, California wastewater sludge incinerator ash [4]. Gold and silver concentrations as high as 32 and 680 mg/L were found. The sludge was reported to have a greater value than much of the ore from the mines of Comstock in Virginia City, Nevada in its heyday.

Although Ontario sludges have not been found to be as valuable as this, some do have significant concentrations of valuable heavy metals. All that is lacking is an economical means of recovery, now the thrust of considerable research effort.

Disposal Techniques

If possible, an option involving reuse or product recovery should be the first sludge disposal process considered. Certain factors, however, may preclude reuse and direct disposal may have to be applied. There are several disposal options available and each alternative should be thoroughly investigated. Disposal options include application to sanitary landfills, incineration, ocean disposal, and underground disposal. Ocean disposal, although widely used elsewhere is not a common disposal method in Canada and its suitability is currently being seriously questioned all over the globe. Therefore, this disposal method will not be discussed any further.

Sanitary landfill

Sanitary landfill of sludge, separately or with municipal solid waste, can be an acceptable means of ultimate disposal of sludge.

The sludge must be stabilized prior to landfill and daily soil cover must be provided.

The landfill site's geology, hydrology and soil conditions should be considered relative to the need for adequate protection of groundwater, conformation to area land use planning, and provision of an adequate quantity of earth cover.

Adequate maintenance of the landfill site is essential and should include provisions for monitoring groundwater observation wells, surface water and sludge and soils for heavy metals, persistent organics, pathogens and nitrates. Leachate and runoff from a sanitary landfill should be minimized and when necessary, collected and suitably treated.

Incineration

In this assessment, incineration is considered as an ultimate sludge disposal technique even though the produced ash must still be disposed of. This is usually accomplished by disposal to a sanitary landfill.

Incineration of sewage sludge achieves complete sterilization along with its primary purpose of organic solids and volume reduction. The volume of incinerator ash is generally about one-tenth that of the concentrated (25% dry solids) digested sludge. Air pollution is a major concern with sludge incineration. However, with proper pollution control equipment the stack gases can meet the most stringent regulations currently in effect in Canada.

The most popular design for sludge incineration has been the multiple-hearth furnace, but more recently interest has been focused on the rotary kiln and fluidized bed furnace as alternative incineration devices.

Some of the problems associated with incineration are the high cost of pretreatment (dewatering) and the traditional need for an auxiliary source of fuel to sustain combustion, although adequate dewatering to in excess of 30 to 35% volatile solids should ensure autogenous combustion. Mixing sewage sludge with other combustible urban waste products is another way of achieving autogenous combustion. The incorporation of heat recovery and/or power generation facilities, could considerably improve the economic viability of sludge incineration methods.

Recent studies carried out at London, Ontario [5] with the use of waste paper pulp to condition the sludge, achieved high solids concentrations following dewatering and increased the calorific value of the dewatered sludge.

Underground disposal

Disposal of toxic and hazardous industrial wastes in underground caverns, abandoned mines, as well as through deep well injection, has fairly widespread acceptance. These techniques could be used for the disposal of wastewater sludges for either interim storage or ultimate disposal, but economics will probably minimize such practice.

PROCESSING REQUIREMENTS FOR DISPOSAL OPTIONS

No matter what the ultimate sludge disposal method considered, some processing will be required to best prepare the sewage sludge for that particular disposal option. The selection of a particular sludge disposal option may well dictate the processing steps required. For

example, selection of incineration presupposes dewatering of the sludge, and dewatering is generally preceded by a conditioning step.

Processing of sludge prior to ultimate disposal generally involves one or more of the following unit processes: thickening, stabilization, conditioning and/or dewatering.

Thickening

Thickening refers to the separation of some of the free water from the solid particles of sludge, the purpose of which is to reduce the volume of sludge to be stabilized, dewatered or disposed of. Thickening a 1% sludge to 6% solids reduces the volume of sludge to be handled by a factor of over 5. This reduction can provide significant savings in the cost of digestion, dewatering or other downstream processes. Three commonly used methods for sludge thickening are gravity, flotation and centrifugation.

Gravity thickening of raw or digested primary sludge is almost always an efficient and economical process, while gravity thickeners are relatively inefficient in processing waste activated sludge and mixtures of raw primary and waste activated sludge. Anaerobically digested sludge is normally thickened by gravity in the secondary digester.

Use of the dissolved air flotation process for thickening of waste activated sludge is increasing in importance because of its reliable and effective results. Solids concentration increases of waste activated sludge from 0.25-2.5% to 4-6% can be readily achieved by this process.

Centrifugal thickening of waste activated sludge has not yet been widely applied in Canada but recent improvements to the solid bowl and disc units may make them more competitive. Centrifuge use is mainly directed towards dewatering.

Stabilization

Sludge stabilization processes are aimed at reducing the rate of putrescibility of sludge while at the same time reducing pathogenic organism content. Some form of stabilization is generally recommended for all sludge treatment and disposal options, primarily because of

odour problems associated with the processing of raw sludges. Major types of stabilization processes are anaerobic and aerobic digestion, chemical treatment and heat treatment.

Anaerobic digestion has always been the most common method of sludge stabilization and it is again receiving renewed interest because of potential benefits of methane production, new design alternatives and the present emphasis on land utilization of digested sludge.

Recent interest in aerobic digestion is aimed at lower capital costs than anaerobic digestion, lower supernatant strength and exothermic heat production capable of raising the temperature of sludge to the pasteurization range [6]. Disadvantages of aerobic digestion over anaerobic digestion include higher operating costs due to air supply requirements and poorer thickening and dewatering characteristics of the digested sludge.

Chemicals most commonly used for sludge stabilization include chlorine and lime but very high dosages of each are required.

Heat treatment in the form of pasteurization and low pressure oxidation processes may be used in place of mesophilic, aerobic and anaerobic digestion.

Conditioning

In addition to free water between sludge particles, sludge also contains bound water (either chemically held near the surface or in capillaries between particles) and intraparticle water (within cell membrane). Conditioning is designed to alter the nature of the sludge to an extent that the release of all the free water and some of the bound and intraparticle water becomes possible during subsequent dewatering. Certain conditioning processes such as heat treatment may also effect some sludge stabilization.

The two basic techniques used for conditioning involve chemical addition or thermal treatment; chemical addition employing either inorganic compounds containing aluminum or iron and calcium, or organic polyelectrolytes.

Traditionally, inorganic chemicals such as aluminum sulphate of ferric chloride plus lime have been used for sludge conditioning. Such

conditioning, however, requires the handling of large volumes of corrosive chemicals with associated storage, handling and feeding problems.

Organic polymeric coagulants and coagulant aids developed within the past 20 years are rapidly gaining acceptance for sludge conditioning. Their popularity is due to their ease in handling, low dosage requirement and resultant small storage space needs, and their effectiveness. The effectiveness of a particular polymer, however, is extremely dependent upon the sludge characteristics, and polymer selection can be a very time consuming proposition with possible seasonal variation in a particular polymer's effectiveness.

Sludge may also be subjected to heat to improve its dewaterability through several proprietary processes. Conditioning by heat treatment produces the most readily dewaterable sludge, as the high temperatures employed denature the proteins (releasing chemically bound water) and disrupt cell walls (releasing cell water).

The major variables of the heat treatment process are temperature, pressure and time. The temperature of most processes ranges between 350 - 400°F at a pressure of between 350-425 psig and residence time of 20 minutes to one hour.

Some of the problems plaguing the heat treatment process include high COD return liquors, corrosion, odours, high operating costs and serious safety hazards. Because of these problems and the need for a high degree of operating skills, interest in this conditioning alternative has been slow to spread. Coupled with incineration and heat recovery, however, the process holds great promise and is currently the only method for ensuring the achievement of an autogenous sludge where sludge alone is being incinerated. In addition, heat treatment has proved to be equally effective on all sludges.

Dewatering

Sludge dewatering is the process whereby any remaining free interparticle water together with some of the intraparticle water is removed from liquid sludges so as to change their physical form from liquids to semi-solids. An ideal dewatering operation should remove a maximum of water while capturing practically all the solids in the dewatered cake at minimum cost.

The technology and design of all dewatering equipment is constantly under development. Each type should therefore be given careful consideration using the most up-to-date information. Many factors which are peculiar to each particular sludge affect the dewatering process. Therefore, pilot tests are highly recommended in determining the applicability of a particular dewatering device on a case-by-case basis.

Dewatering devices include drying beds, lagoons, rotary vacuum filters, centrifuges, filter presses and belt filters.

Drying beds and sludge lagoons are generally used only for the smaller wastewater treatment facilities because of the relatively large land area requirements and relative simplicity of operation. Dewatered sludge from such facilities is generally either disposed of onto agricultural lands or into sanitary landfills.

Vacuum filters and solid bowl centrifuges produce a similar cake solids content (25-30% solids on primary sludge and 15-20% solids on mixed primary plus waste activated sludge). The vacuum filter is considerably more popular in North America than is the solid bowl centrifuge, however, for sludge dewatering. Centrifuges have the advantages of being a totally enclosed process and requiring less space than vacuum filters. They have the disadvantage of requiring more and more highly skilled maintenance.

Plate and frame filter presses have only recently been successfully applied to sewage sludges. The major disadvantages of the filter press over the vacuum filter are the semi-batch mode of operation and frequent requirement for operator attention during cake removal. The greatest advantage of the filter press is its ability to dewater up to a 50% solids content, made possible by operating pressures up to 225 psig.

The belt filters have been relatively recently introduced into the sludge dewatering field but are gaining rapidly in popularity because of their simplicity in operation and low power requirement. Solids cakes similar to or somewhat higher than those from the vacuum filter are achieved.

PRACTICE AND TRENDS IN SOME OTHER COUNTRIES

Waste treatment as well as sludge handling and disposal problems are generally not unique to any one country. The problems are usually similar. However, the scale of the problem and the constraints within which a solution can be obtained will differ between countries. This is dictated by various factors such as: geography, size of country, population density, degree of industrialization, economic state of the country, climatic conditions, etc.

For example it was estimated [9] that in the Federal Republic of Germany the volume of sludge generated in 1975 from municipal waste treatment plants was 20×10^6 m^3/year. This volume is projected to increase to 50×10^6 m^3/year by 1985. Furthermore, this does not include an estimated annual sludge volume of 30×10^6 m^3 from industrial waste treatment systems.

The Federal Republic of Germany is not unique in pursuing a sludge disposal philosophy consisting of process optimization with a view toward:

- low energy demand,
- low operator requirements,
- high degree of operational flexibility,
- minimum of secondary pollution arising from sludge disposal.

Since any sludge disposal option considered ties back to sludge stabilization, thickening and dewatering processes, changes in one influence the others. In the Federal Republic of Germany certain trends in these areas are emerging. For instance, aerobic stabilization of sludge due to waste treatment in oxidation ditches is on the increase. Because of energy consideration (i.e. process heat loss) separate aerobic digestion is not on the increase. Thermophilic, aerobic stabilization (>45°C) of fluid sludges is now in the development stage.

As in other countries, the practice of chemical conditioning of sludges before mechanical dewatering is widespread. Inorganic conditioners (metal salts, lime and ash) are most popular in application of sludges to be dewatered using vacuum filters and filter presses. Organic conditioners (polyelectrolytes) are most frequently used with centrifuges and filter belt presses.

Thermal conditioning of sludges is only considered for large treatment plants. To date, only a few systems have been installed in the Federal Republic of Germany.

Pasteurization of sludges in the Federal Republic of Germany is not widespread. The most popular process consists of thermal pasteurization in the 65°C to 75°C temperature range. Development work using gamma-irradiation of sludge is in progress near Munich. High energy electron bombardment of sludge for pasteurization is still at an experimental stage.

In the Federal Republic of Germany, the majority of sludge thickening operations consist of gravity systems operated in the batch mode. A trend toward continuous sludge thickening is more recent. Flotation as a process for sludge thickening is only in its infancy.

In the area of natural sludge dewatering the use of landfill (sludge dumps) as well as drying beds is extremely popular. This is especially true of smaller communities.

The general trend in the Federal Republic of Germany as it affects dewatering processes is an increase in mechanical dewatering processes consisting of either centrifuges, or belt filter presses. Vacuum filters appear to be falling into disfavour.

For the ultimate disposal of sludges, the trend is to go to incineration processes using multiple hearth, rotary kiln or fluidized bed technology.

New developments concern aerobic composting of dewatered sludges with sawdust as an additive.

Land application of dewatered or composted sludge is popular and accounts for approximately 15-20% of all sludge produced. Of this, 50% is applied to grass land and plowed fields in liquid form; the remainder is applied as a dewatered sludge. Liquid sludge application to land is generally practiced by smaller waste treatment installations using tanker trucks. A few spray irrigation installations using pasteurized and digested liquid sludge have also been installed and are operating most satisfactorily.

Switzerland produces approximately 2×10^6 m^3 of sludge per annum [10]. Of this, 80% is applied in liquid digested form on farmers'

fields. As in other countries, the fertilizer value of sludge is receiving more recognition and is increasing in importance.

In the United States [11] sludge production is expected to increase from 4.8×10^6 dry tons/year to 6.7 dry tons/year between 1972 and 1985. The trend in sludge disposal options is for increased application to land (from 20% in 1972 to 25% by 1985) and incineration (from 25% in 1972 to 35% by 1985). Disposal of dewatered sludge to landfill is expected to remain constant at 40%.

In the United Kingdom approximately 50% of the sewage sludge disposed on land is produced by the larger treatment plants. The current trends are for increased mechanical dewatering of sludge and the direct disposal of liquid sludge by tanker to agricultural land [12]. It may be interesting to note that in the United Kingdom application of untreated sludge to agricultural land is practised at a significant scale. Opinions on the acceptability of applying untreated liquid sludge to agricultural land differ.

This brief examination of practice and trends concerning sewage sludge handling and disposal in some other countries illustrates three points:

1. Sludge quantities are increasing rapidly.
2. The search for more cost-effective solutions which are environmentally safe and acceptable to the public is accelerating.
3. Increased awareness of energy conservation and resource recovery requirements makes sludge application to land a sound and popular management solution in many countries.

SLUDGE PRODUCTION IN ONTARIO

The Province of Ontario has some 350 wastewater treatment facilities with a combined treatment capacity of 976 million imperial gallons per day (MIGPD). In these facilities some 860 tons of BOD_5 and 960 tons of suspended solids are removed every day resulting in the daily production of an estimated five million gallons of sludge which must be adequately disposed of. Over 180 of these treatment facilities, with a hydraulic capacity of 835 MIGPD, now utilize chemical precipitation

processes for phosphorus removal. This flow represents approximately 85% of the total capacity of all plants in the province.

Sludge production at a particular plant is influenced by a number of variables. For biological sludge production, the amount of sludge produced varies with the nature of the substrate being oxidized and the amount of inerts in the raw sewage flow. The type of process used also greatly affects the amount of biomass produced. Sludge production is higher in winter than in summer because of the reduced auto-oxidation rate at low temperatures.

Sludge production from the phosphorus removal process is dependent upon the chemical used, the dosage required and the point of application. On the latter point alone, generally 30 to 40% more chemical is required for the same level of phosphorus removal if that chemical is added to the primary clarifier rather than to the secondary process.

The total volume of sludge produced from biological and combined biological-chemical processes is also influenced by clarifier efficiency, sludge recycle rate, total plant performance and degree of operator control.

Sludge production data for Ontario were obtained from a survey of municipal wastewater treatment plants carried out in 1975 [7]. The survey included data collected from primary and secondary facilities, prior to and following the installation of phosphorus removal facilities. A summary of the sludge production data obtained in that study is presented in Tables 1 and 2, respectively. Table 2 represents data for conventional activated sludge plants with the addition of metal salts to the aeration tank.

Based upon the results of the Ontario survey, some generalized design data for sludge production are shown in Table 3.

Keeping in mind the many factors which influence the quantity of sludge produced in a particular facility, the standard rule-of-thumb that sludge volume approaches 0.5% of the influent hydraulic load to a conventional plant is a fair approximation. By using this estimate, the apparent margin of safety would allow upgrading of a conventional plant without major expansion of sludge handling facilities.

TABLE 1

Primary Process Sludge Production Data

Description	Units	Primary Sludge Production: Prior to Chemical Addition	Primary Sludge Production: After Chemical Addition	Percent Change
Volume	gal/10^6 gal	2,000	3,200	+60
	gal/capita	0.29	0.46	-
	% of influent Q	0.20	0.32	-
Mass	lbs/10^6 gal	1,202	1,668	+39
	lbs/capita	0.17	0.24	-
Solids	percent	6.0	5.2	(-0.8)
Number of Plants	-	7	7	-

TABLE 2

Conventional Activated Sludge Process Sludge Production Data

Description	Units	Prior to Chemical Addition	After Chemical Addition	Percent Change
Volume	gal/10^6 gal	3,810	5,144	+35
	gal/capita	0.55	0.75	-
	% of influent Q	0.38	0.51	-
Mass	lbs/10^6 gal	1,725	2,175	+26
	lbs/capita	0.25	0.31	-
Solids	percent	4.5	4.3	(-0.2)
Number of Plants	-	15	15	-

TABLE 3

Sludge Production - Suggested Design Data*

System	lbs pcd	Sludge Quantity: Volume % of Influent	Sludge Quantity: lbs ds/10^6 gal
Conventional Primary	0.17	0.20	1,200
Upgraded Primary	0.24	0.32	1,675
Conventional A.S.	0.25	0.38	1,725
Upgraded A.S.	0.31	0.51	2,175

* Based on Q = 145 gpcd
ds = dry solids
pcd = per capita/day

NATURE AND CHARACTERIZATION OF SLUDGES

The composition of sewage sludge produced from a municipal wastewater treatment plant varies widely from one locale to another depending upon a variety of factors. Such factors include the type of treatment process used, the presence or absence and the nature of industrial wastes, the presence or absence of storm water, the type of community and the quality of the community's raw water supply.

Because the composition of sludges varies so greatly from one municipality to another, generalized statements about their nature are of limited value, as are average composition data. Some generalization, however, is possible.

Raw primary sludges almost universally settle, thicken and dewater with relative ease, compared to secondary biological sludges, due to their coarse, fibrous nature. Although anaerobic digestion of primary sludges frequently makes them somewhat more difficult to thicken and dewater, dewatering results are still generally good at relatively low costs.

Waste activated sludges show much greater variation in dewatering characteristics than do primary sludges. They are much finer, and largely of cellular organic material with a density very nearly that of water, and consequently are much more difficult to thicken and dewater than are primary sludges.

Chemical sludges are greatly affected by the chemical coagulant used. Generally, alum and iron coagulants produce gelatinous flocs which are difficult to thicken and dewater, while lime coagulation produces a sludge which will normally readily thicken and dewater. The sludges produced by the co-precipitation of phosphorus (the process used in Ontario for phosphorus removal) are generally only slightly more difficult to dewater than are combined primary and waste activated sludges.

Besides the nature of sludges varying drastically from one plant to another, so does their chemical composition. Again the composition is affected by type of process, quality of influent sewage, etc. and is specific to each municipality.

Data on the composition of Ontario sewage sludges is presented in Table 4. This data is presented solely to indicate the range of concentrations of various constituents found in sludges. Any further

TABLE 4

Sludge Characteristics

Parameter		Group #1* Max.	Group #1* Min.	Group #2** Max.	Group #2** Min.	Group #3*** Max.	Group #3*** Min.
Capacity		3	0.57	50	0.25	10	0.13
Total Solids	(%)	10.6	4.4	6.6	2.4	5.9	0.7
Total Nitrogen	(mg/L)	2,700	700	6,000	1,500	1,800	300
	(%)dry)	2.2		5.9		3.2	
Ammonia N	(mg/L)	600	46	1,000	240	170	9
Phosphorus	(mg/L)	5,600	200	2,300	300	2,200	220
	(%) dry)	2.7		2.1		2.5	
Cadmium	(mg/L)	1.1	0.17	2	0.08	1.9	0.08
Chromium	(mg/L)	80	2	520	3	22	0.89
Cobalt	(mg/L)	1.2	0.12	0.95	0.18	0.8	0.1
Copper	(mg/L)	67	21	70	4	130	10
Lead	(mg/L)	140	3	55	0.9	52	4
Molybdenum	(mg/L)	1.9	0.23	18	0.23	0.5	0.2
Nickel	(mg/L)	26.1	1.0	43	0.2	9.3	0.3
Zinc	(mg/L)	500	5	430	15	370	1
Mercury	(ug/L)	82	4.2	68	3.9	4.3	1

* Group #1 - Primary Plants with Anaerobic Digesters

** Group #2 - Conventional Activated Sludge Plants with Anaerobic Digesters

*** Group #3 - Extended Aeration Plants with Aerobic Digesters or Aerated Holding Tanks

interpretation of the data could be misleading since the concentration of each constituent is specific to each particular sludge. The upper and lower limits presented, however, suggest that one could expect a particular sludge to fall between them unless there is some very peculiar industrial contribution.

Table 4 presents some of the more noteworthy constituents of liquid sewage sludges. The data for these tables is taken from the 1976 Operating Summary, Water Pollution Control Projects, prepared by the Ontario Ministry of the Environment.

Group #1 contains data obtained from seven primary treatment plants ranging in design capacity from 0.57 to 3.0 MIGD. All the data represent anaerobically digested sludge.

Group #2 represents data from twenty conventional activated sludge plants ranging in capacity from 0.25 to 50 MIGD. Again the data are for anaerobically digested sludge.

Group #3 presents similar data from twelve extended aeration plants ranging in capacity from 0.13 to 10.0 MIGD. In this case the samples represented are those from aerobic digesters or aerated holding tanks.

Of note, particularly where land utilization of the sludge is considered, is the total Kjeldahl and ammonia nitrogen contents of the sludge. The total nitrogen content of the anaerobically digested conventional activated sludge process sludge is considerably higher (5.9%) than that of either of the other sludges.

The concentrations of other parameters are quite similar between the three sludges, although the range is generally much wider for the conventional activated sludge plants. This, however, may be a direct reflection of the number of plants sampled. One can expect the metal concentrations of extended aeration plant sludges to be somewhat lower than either primary plant or conventional secondary plant sludges. This is perhaps because the extended process is more likely to be used for smaller, residential type communities.

PRACTICES AND PREDICTIVE TRENDS FOR ONTARIO

Present sludge disposal practices in Ontario include incineration, spreading on farmland, disposal to sanitary landfills, lagooning, and dewatering and stockpiling for home garden usage.

The relative popularity of each of these practices was determined in a recent survey of some 155 water pollution control plants in the province [7]. Table 5 has been derived from the extrapolation of this data to the 210 mechanical plants in the province. Out of 210 plants, 133 practice sludge utilization on agricultural land, indicating the popularity of this practice.

Table 6 converts this data into quantity of sludge disposed of by each of the methods. As noted, incineration at three municipalities accounts for almost 40% of the total sludge disposal. With the startup of incinerators currently under design or construction at four Ontario plants, this percentage will increase from 40 to about 65%. Land utilization presently accounts for 34% of the sludge.

Sludge disposal to farmland is certainly not new to Ontario. The cities of Kitchener and Guelph have used this method of disposal for some 45 years. The above survey showed that sludge application to farmland is increasingly favoured by smaller municipalities, however, since over 50% of the plants surveyed started this practice within the last five to seven years. No doubt, economic benefits and simplicity of operation are major factors affecting this trend.

Looking to the future we can expect land application to continue as a popular method of ultimate sludge disposal. The practice, however, will be subjected to guidelines which will generally recommend reduced application rates and thus require more land. They will also limit the application of heavy metals and in effect show some sludges to be totally unacceptable for any land utilization scheme because of high metal levels. The future acceptability of these sludges will be determined by the effectiveness of industrial waste discharge bylaws in reducing metal levels discharged to the sewer system and therefore the levels of metals in the sludge.

Such guidelines, however, if adequately adhered to should make the practice more acceptable as a utilization practice and ensure its future continued use.

Landfilling, if properly carried out, can be an effective means of sludge disposal. Tighter regulations, however, are rapidly diminishing the availability of suitable sites. As landfilling may be the only

TABLE 5

Current Sludge Disposal Practices in Ontario

Numbers of Plants

Disposal Practice	*No. of Mechanical Treatment Plants*	*% of Total*
Application to Agricultural Land	*133*	*63.2*
Disposal by Landfill	*23*	*11.0*
Dumpsite plus mine tailings	*19*	*9.0*
Incineration	*3*	*2.0*
Disposal by other means	*32*	*14.8*
TOTAL	*210*	*100.0*

TABLE 6

Current Sludge Disposal Practices in Ontario

Quantity of Sludge

Method of Disposal	*Amount of Sludge Disposed (dry tons/year)*	*% of Total*
Incineration	*70,006*	*39.8*
Application to Agricultural Land	*59,754*	*34.0*
Disposal by landfill	*39,513*	*22.5*
Disposal by other means	*6,512*	*3.7*
TOTAL	*175,785*	*100.0*

alternative left to those municipalities with sludges unsuitable for land utilization, we may see a slight increase followed by a leveling off or reduction in this practice.

Incineration is definitely a promising sludge disposal method for larger municipalities. It is a process, however, which offers little opportunity for net energy recovery when handling sewage sludge alone and, therefore, in view of the rising costs of fuel, more emphasis will have to be placed on achieving an autogenous sludge cake for this practice to survive. Incineration is a very complex process and is really not suitable, under present day technology, for plants under 15 to 20 MIGD capacity. Since over 90% of the plants in Ontario have a design capacity of 10 MIGD or less, incineration is not a viable option for the majority of Ontario municipalities.

Promising areas for the future are co-incineration and co-pyrolysis of sludge with solid waste; methods not requiring supplemental fuel. Co-pyrolysis may also produce usable byproducts such as fuel gas and char. Co-incineration with municipal refuse or other organic material may lead to economic heat recovery and/or energy production schemes.

Certainly disposal costs as a percentage of wastewater treatment costs will continue to rise. The benefit of proper sludge disposal, however, will be a more secure environment for now and for future generations.

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A METHODOLOGY FOR IMPROVED SLUDGE SAMPLING AND CHARACTERIZATION

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INTRODUCTION

With increased concern for sludge handling, treatment, and disposal, a reliable and efficient sampling strategy is required for sludge characterization. New guidelines for sludge disposal on land, such as those being formulated in Ontario, will require that sludge constituent concentrations be measured to permit regulation of sludge application rates. This implies a direct need for efficient sampling guidelines which minimize sampling and analyses costs and maximize the usefulness of the data collected.

This presentation describes a project which was carried out from the Wastewater Technology Centre in Burlington (1974 to 1975) to provide recommendations for rational sampling strategies for monitoring anaerobically digested sludges. Data were collected to identify important sources of variation, to suggest when sampling was most useful, and to provide estimates of relative precisions in constituent concentrations (Monteith and Stephenson, 1978). The study was performed at five Ontario water pollution control plants (WPCP's); the conventional activated sludge process was used at each plant with anaerobic digestion of raw and waste activated sludges. No changes were made in routine operating procedures at these plants, and no attempt was made to control the variations observed. Analyses included nutrients (TKN, NH_3-N, phosphorus), metals (Fe, Al, Ni, Cu, Zn, Pb, Cd), and solids. Liquid sludges were sampled both at plants from which sludges were hauled by truck to land disposal sites (batch mode) and at plants where sludges were dewatered (semi-continuous mode).

This paper discusses TKN, NH_3-N, Zn, and solids variations for two of the plants studied: one batch mode and one semi-continuous mode plant.

The principle objectives of the study were:

1. to identify and compare the sources of constituent variability in digested sludges by determining whether variations arose from sample handling and analytical determinations, from changes in composition with time, or from inherent heterogeneity; and
2. to determine, for a given number of samples, the obtainable precisions in mean constituent concentrations, and to identify an appropriate sampling frequency for monitoring anaerobically digested sludges.

PROCEDURES

Selection of Plants

The two plants described in this presentation are the Chatham and Oakville S.E. WPCP's. Table 1 describes the plants, and provides some operational data to highlight their operation. At one plant, the Chatham WPCP, sludge was dewatered using a centrifuge on weekdays during the daytime shift. Samples were collected on 15 consecutive working days in a three-week period (March 3 to March 15, 1975). Within each day, five samples were systematically collected at 90-minute intervals from the feed to the centrifuge in an ordered sequence through the operating day. Each of these samples was replicated three times giving a total of 15 samples per day. These three replicates were collected within a few minutes of one another (<5 minutes) to provide an estimate of variation owing to sample retrieval, testing, and all unaccountable sources of variation. A supplementary sampling survey was conducted to monitor nutrient and heavy metal variatons during a longer period (six months). Further discussion of the sampling design and data analysis procedures is given in the section titled Sampling Designs.

At the second plant, the Oakville S.E. WPCP, secondary digested sludge was discharged batchwise to tank trucks. The sampling program extended from July 16 to September 10, 1975. Sludge was discharged once per week during this time period, except one week when wet weather prevented sludge withdrawal; data were obtained for all eight hauling days of the nine-week interval. A total of 33 truckloads was discharged for an average of about four batches (107 m^3) per hauling day; the

TABLE 1. DESCRIPTIONS OF WPCP'S AND OPERATIONAL DATA

	Chatham	Oakville S.E.
Population Served	34,000	16,000
Raw Sewage Flow (m^3/day)	20,500	7,260
(MIGD)	4.51	1.60
Chemical Addition	$FeSO_4$	-
Sludge Dewatering	centrifuge	-
Sludge Disposal	cake disposed on plant site	liquid sludge to farm land
Acids:Alkalinity Ratio In Primary Digester	0.17	0.06
Organic Loading Rate To Primary Digester (kg VS/m^3/day)	1.48	0.19
Temperature (°C)	33	34
Gas Production (m^3/kg VS added)	0.43	1.24

maximum was five batches per hauling day. Three samples were systematically collected from the input to each truckload; truck loading time varied between 14 and 20 minutes, and time between the three samples per batch was about seven to eight minutes. One sample per batch was randomly selected and replicated to permit estimation of error variance. Time between batches was 60 to 75 minutes.

Sampling Designs

This outline is given to indicate the statistical methods used to interpret the data; it would prove difficult to interpret the observations, here, without these techniques.

Sampling designs were adapted from procedures used in the process industries (Davies, 1956; Hald, 1952), in agriculture (Snedecor and Cochran, 1967), and in marine sediment sampling (Kelly and McManus, 1969). These procedures all included analysis of variance (ANOVA) as their principal data analysis format. In this study, the components of variance of each constituent were separated and estimated. The estimates were used to attribute the observed variability to:

1. sample retrieval, testing, and all unaccountable sources of variation;
2. variations within a batch of digested sludge discharged to a tank truck;
3. within-day variations in the liquid sludge feed to a dewatering device at plants where sludge was dewatered;
4. batch-to-batch variations within a day at plants where liquid sludge was discharged to tank trucks;
5. day-to-day variations; and
6. week-to-week variations.

Using these groupings, the components of variance identified the greatest sources of contribution to the system's variability. Combined with statistical tests of significance, these components revealed the most productive sampling arrangement.

Obtainable precisions in mean constituent concentrations were estimated using a relationship between sample size, n, and the measured relative standard deviation, RSD. Figure 1 illustrates the relationship for a range of desired precisions (allowable error) from 0.10 $\bar{x}$ to 0.50 $\bar{x}$ (mean). Details of this figure's construction are available elsewhere (Monteith and Stephenson, 1978). Use of this technique indicates the total sample size, n, but it does not indicate the most efficient sampling arrangement; the components of variance must be assessed to obtain this.

Insight into long term variability (about one year) was obtained by examining digested sludge total solids concentrations from plant records, and by conducting a supplementary survey to measure nutrient and heavy metal concentrations. Doing this, the physical and chemical variability were revealed during a time period sufficient to show characteristics not evident during the short term sampling surveys described above. Plant records of total solids concentrations from the Chatham WPCP were analyzed for a period extending from July, 1973 to December, 1975, using the autocorrelation function, ACF (Box and Jenkins, 1970). Digested sludge total solids concentrations had been determined for one grab sample once per weekday by the plant's staff; these data were condensed to an average weekly concentration and the ACF was calculated. This

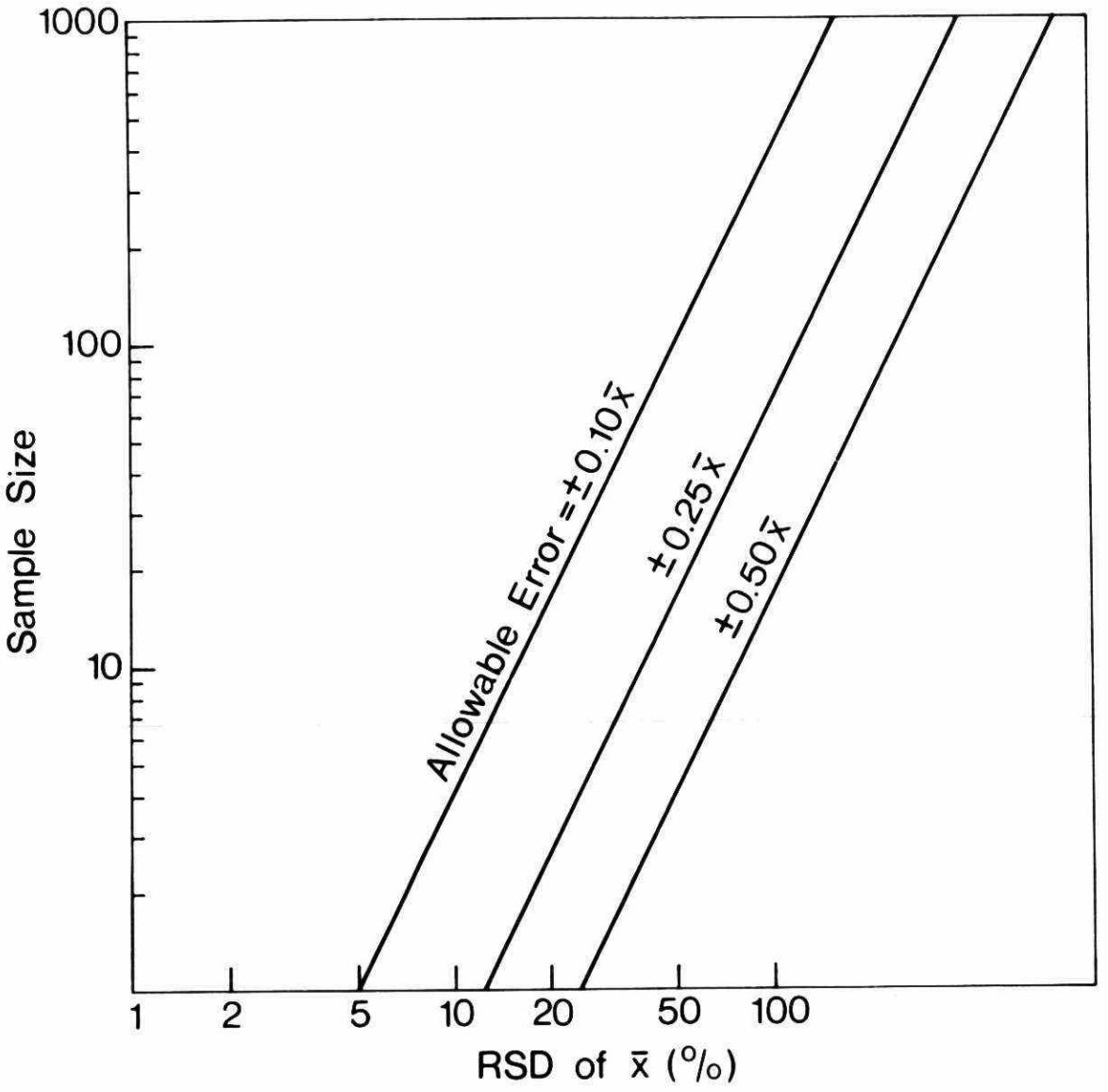

FIGURE 1. SAMPLE SIZE DETERMINATION PLOT

long sequence of observations provided an opportunity to identify any serial dependency (autocorrelation) in the data, periodicities, and variability. Details concerning these determinations and their interpretation are described by Box and Jenkins. A sampling frequency was estimated from the ACF using the technique suggested by Bendat and Piersol (1966). This technique ensures that variations in a system are adequately monitored without gathering correlated and redundant data.

The supplementary sampling survey was designed to complement the plant records with information about nutrient and heavy metal variabilities. The survey was conducted at the Chatham WPCP from June 23 to November 14, 1975. Based on the results of the short term study, three grab samples of centrifuge feed sludge were taken; one after the start, one near the mid-point, and one before the end of each day's centrifuge run by the plant staff. These three grab samples were then combined to make a daily composite sample for TKN, NH_3-N, total solids, Ni, Cu, and Zn analyses. A survey was simultaneously conducted at this plant by another agency. Every second week, five grab samples were collected, on each weekday, and composited for analysis. The results of that survey were qualitatively compared with the results of the supplementary survey.

OBSERVATIONS AND DISCUSSION

Chatham WPCP (Semi-Continuous Mode)

The data were reduced and plotted according to the sampling design for the March, 1975 period. Each point plotted in Figure 2 represents the average of 45 samples (5 days per week x 3 repeats per sample x 3 weeks) collected during each week-day. The sample sequence, numbered one through five on the figure, represents the order of the samples taken within the operating days. The sample numbered one was collected during the morning; the last sample, numbered five, was collected late in the afternoon. Figure 2 clearly indicates what occurred on the average during an operating day. Though the variations from sample-to-sample were not great, the constituents associated with the solid phase (TKN, Zn) tended to decrease consistently during an operating day. Ammonia nitrogen was associated with the liquid phase, and did not display this decrease.

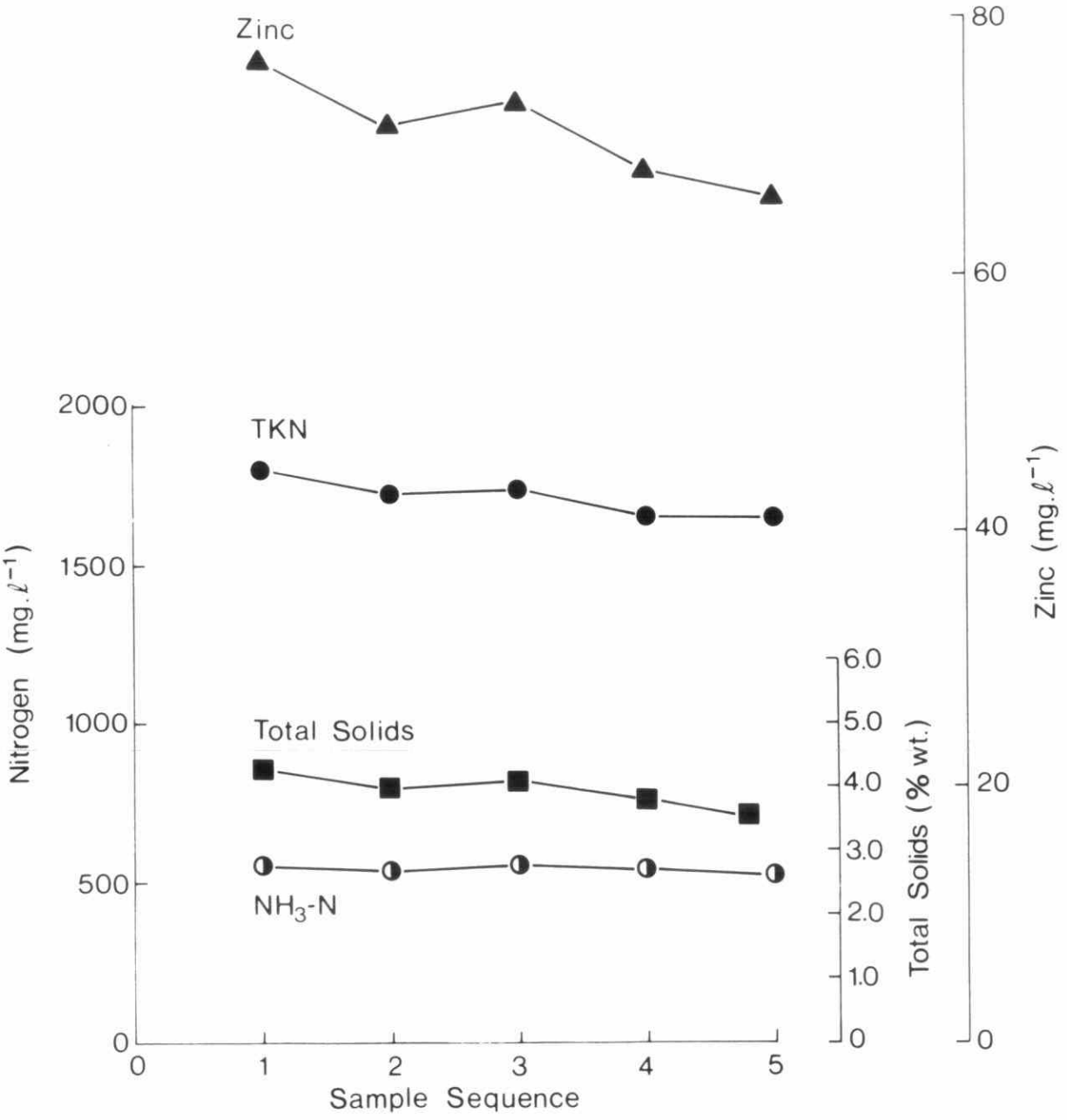

FIGURE 2. MEAN PARAMETER CONCENTRATIONS BETWEEN SAMPLES WITHIN DAYS, CHATHAM WPCP

Figure 3 depicts a plot for the day-to-day variations which occurred within weeks. The daily sequence represents Monday through Friday; here, each day's constituent concentrations are the averages from that day during the three sampling weeks. With the exception of TKN concentration between the first and second days, there was less variation between days within weeks than between the samples within a day. There was little evidence to suggest that systematic variations existed between the days within a week, even though the solids and TKN concentrations decreased towards the fifth day of the sequence; this contrasted with the results presented in Figure 2.

Variations between the three consecutive sampling weeks are shown in Figure 4. Inspection of the original data revealed three distinct levels between these weeks; within each week variations similar to those shown in Figure 3 were apparent. Further discussion of variability between weeks is given below with the discussion of plant records for total solids concentrations.

The analysis of variance (Table 2) provided an unbiased estimate of the constituent variability of sludge from the Chatham WPCP. The ANOVA indicated that all factors made a significant contribution to the variabilities observed, except total solids variations between days within weeks. For the solids concentrations, there was no evidence to suggest that variations between the days within any week were due to factors not already present within each day. The estimates of the components of variance, s^2, suggested that the greatest variability within weeks was a result of variations between samples within days. TKN concentrations were an exception to this for reasons unexplained. For total solids and zinc, the variances, s^2, for the within days factors were also greater than the between weeks factors. Variations from sample handling and analytical determinations contributed the least to variability. This analysis of the data clearly demonstrates that variability within a day is the most important source of variation during time periods of one or two weeks.

Since within-day variability is highly significant, it is necessary to design routine sampling strategies to take this into account. A more efficient estimate of sludge constituent concentrations

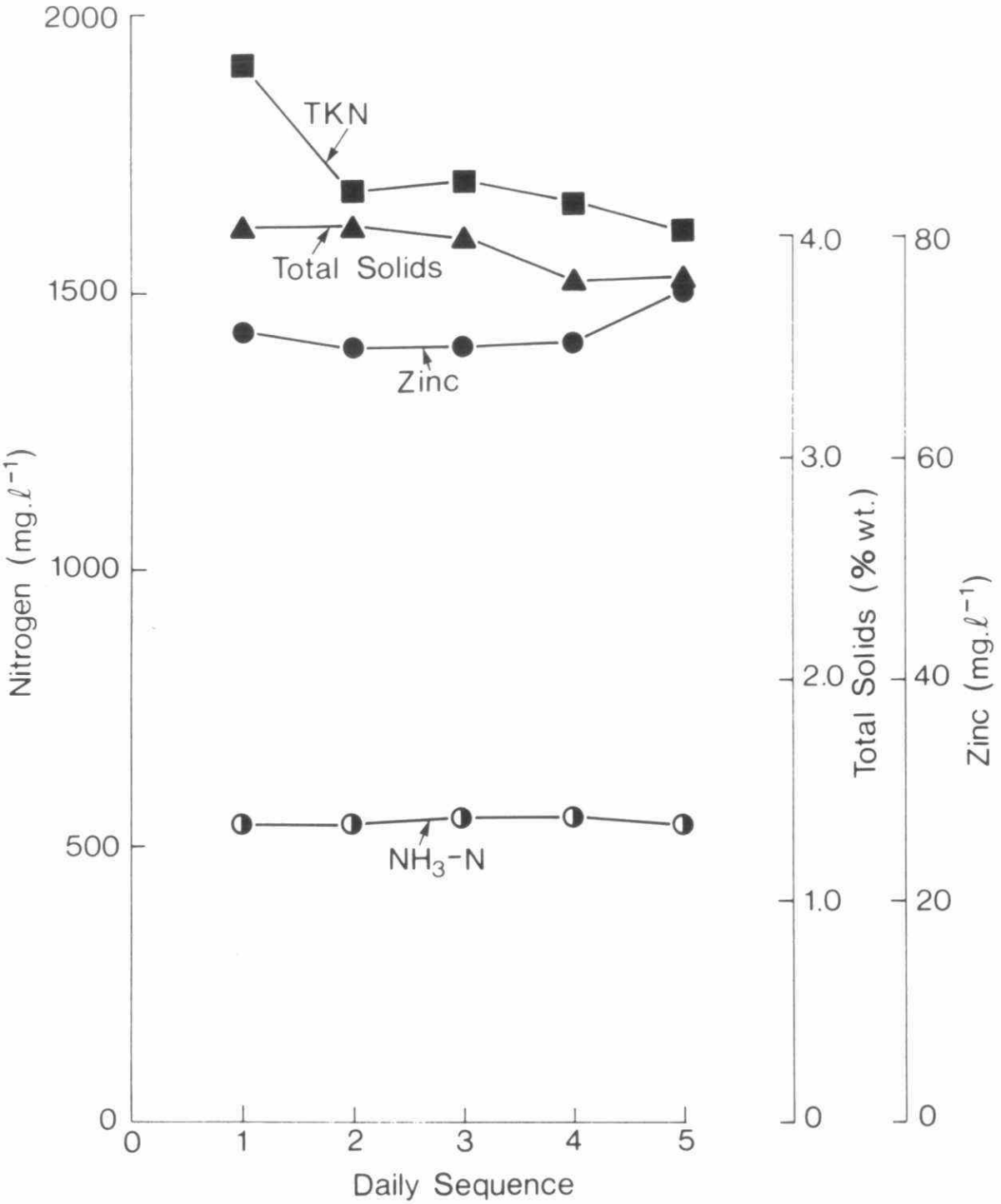

FIGURE 3. MEAN PARAMETER CONCENTRATIONS BETWEEN DAYS WITHIN WEEKS, CHATHAM WPCP

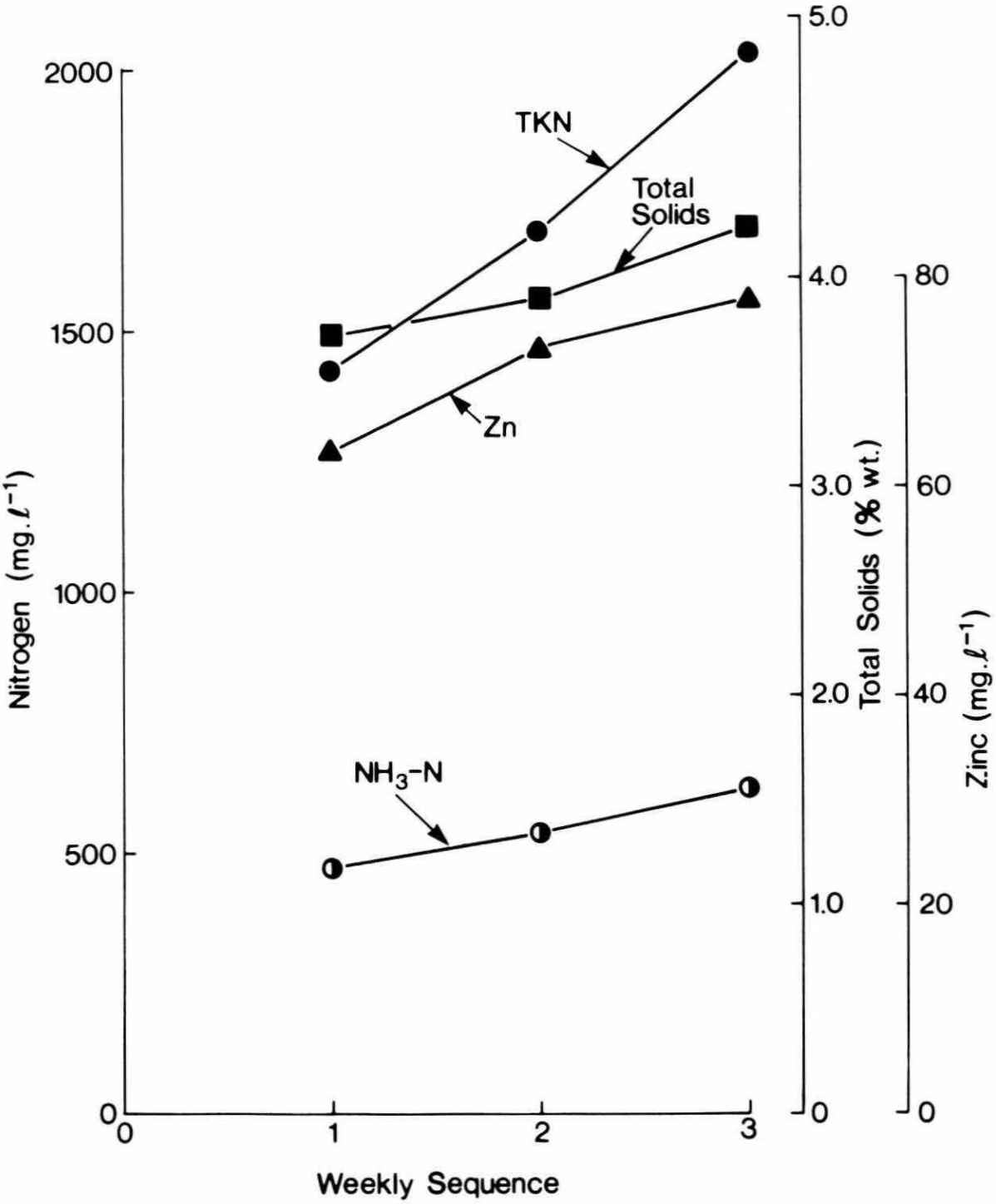

FIGURE 4. MEAN PARAMETER CONCENTRATIONS BETWEEN WEEKS, CHATHAM WPCP

TABLE 2. ANALYSIS OF VARIANCE, CHATHAM SLUDGE

Source of Variation	df	Total Solids			TKN		
		Mean Square	Significance	$s^2(\%)^2$	Mean Square	Significance	$s^2(mg \cdot l^{-1})^2$
Between weekly periods	2	4.823441	*	0.0427594	7,011,136	**	82,296
Between days within weeks	12	1.616485	NS	0.0504925	838,933	**	50,253
Between samples within days	60	0.859098	**	0.2847794	85,144	**	23,560
Between repeats within samples	150	0.00475953		0.0047595	14,464		14,464

Source of Variation	df	NH_3-N			Zinc		
		Mean Square	Significance	$s^2(mg \cdot l^{-1})^2$	Mean Square	Significance	$s^2(mg \cdot l^{-1})^2$
Between weekly periods	2	428,795	**	5,685	4,265	**	49.7
Between days within weeks	12	2,566	*	97	535	*	19.2
Between samples within days	60	1,118	**	313	247	**	74.1
Between repeats within samples	150	179		179	24.6		24.6

* Significant at 95% level.
** Significant at 99% level.
NS Not significant at 95% level.

can be made by concentrating sampling within a day rather than spreading it over several days within a week. At plants where sludge is dewatered, the sample should be a composite of at least three grab samples systematically collected during an operating day. This composite will account for the decline of sludge solids concentration during a day.

Based on the within-day estimates of variability, the RSD of each constituent concentration was estimated (Table 3), and used with Figure 1 to predict the obtainable precision in mean concentration for a sample size of n = 3. The estimated precisions for n = 3 are presented in Table 4. Those constituents associated with the solid phase, including all other metals (Fe, Cu, Pb, Cd, etc.), organic nitrogen, and volatile solids, will require more effort to estimate with the same precision as those associated with the liquid phase. The semi-continuous withdrawal of sludge to the centrifuge resulted in a decrease in solids concentration within a day. The decline of TKN, Zn and other constituents concentrations associated with the solid phase was linked to this effect. Liquid phase constituents, for example, NH_3-N, TDS, volatile acids, and alkalinity, did not respond to this factor, though significant deviations were observed within a day.

Since a three-week period was insufficient to estimate a suitable sampling frequency, 30 months of plant records for total solids concentrations were examined. This record of weekly mean concentrations is plotted in Figure 5. To determine the inherent variation of total solids within one calendar year, the grand mean and RSD were calculated for the arbitrary period May, 1974 to May, 1975. The grand mean was 4.6% solids, and the RSD was 22%. For an RSD of 22%, it can be shown that using Figure 1, 19 samples would be required to estimate the true mean concentration within $\pm$ 10%. Therefore, one sample, collected every two to three weeks during the year, would satisfy this requirement.

The autocorrelation function (ACF) and partial autocorrelation function (PACF) for the data shown in Figure 5 indicated that the digested sludge total solids concentrations were characterized by a mean which was constant with time; the weekly data did not drift from the mean for excessive periods of time. The ACF (Figure 5) also suggested that the observations were not random, and that observations up to four to six

TABLE 3. WITHIN-DAY RSD'S (%) AND WITHIN BATCH RSD's (%)*

		Constituent			
	WPCP	Total Solids	Zinc	TKN	NH_3-N
Within Day	Chatham	14	14	11	4
Within Batch	Oakville S.E.	37	40	23	6

$$*\text{RSD } (\%) = \frac{100\sqrt{s_0^2 + s_1^2}}{\bar{x}}$$

where: RSD = relative standard deviation,

s_0^2 = component of variance between repeats within samples,

s_1^2 = component of variance between samples within days, or within batches.

TABLE 4. OBTAINABLE PRECISIONS ($\pm$%) IN MEAN CONSTITUENT CONCENTRATIONS FOR SAMPLE SIZE n = 3*

		Constituent			
	WPCP	Total Solids	Zinc	TKN	NH_3-N
Within Day	Chatham	16	16	13	5
Within Batch	Oakville S.E.	43	46	27	7

* Estimated at 95% confidence level.

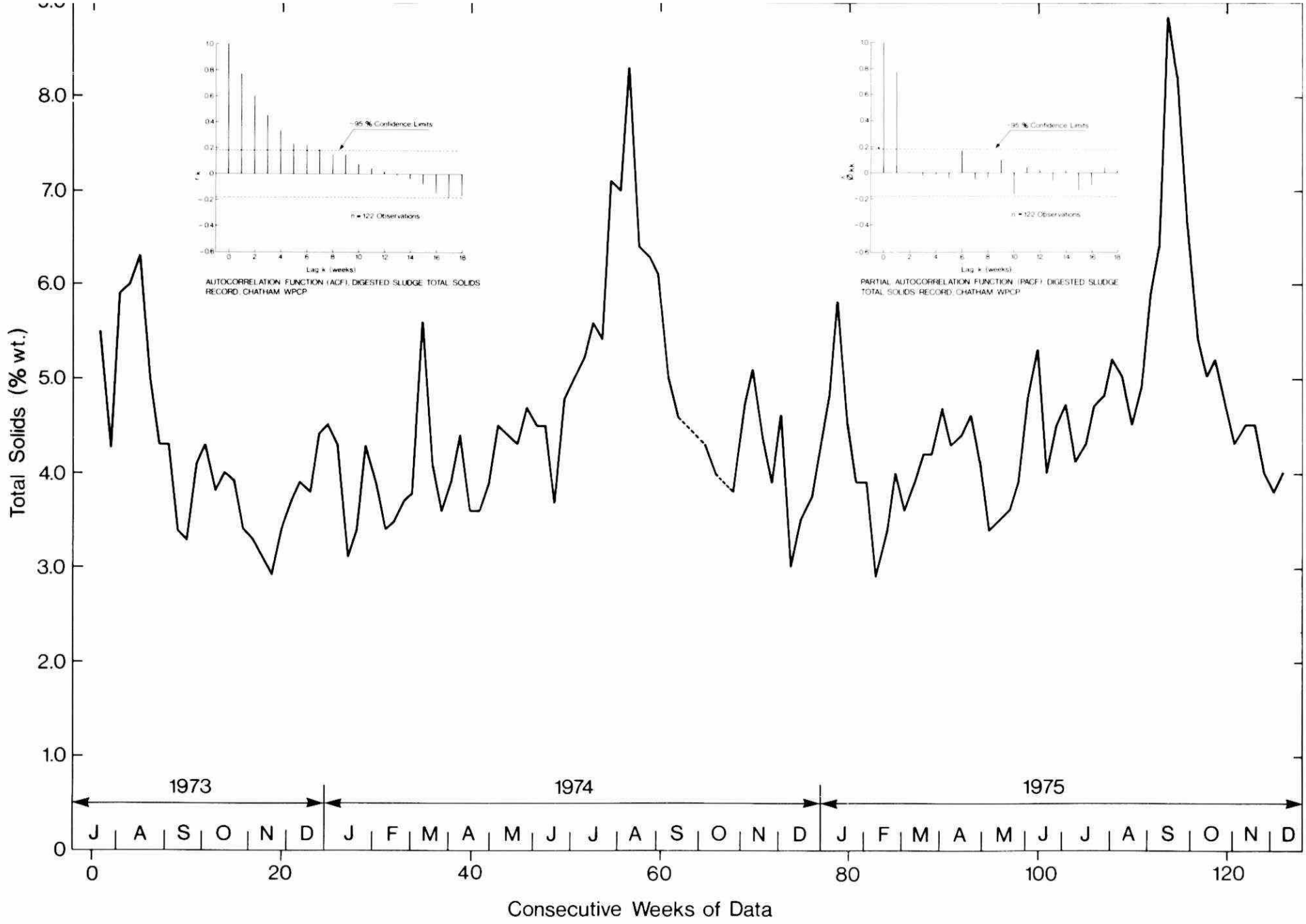
Total Solids (% wt.)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
1973
1974
1975
J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
0 20 40 60 80 100 120
Consecutive Weeks of Data
95 % Confidence Limits
n = 122 Observations
Lag k (weeks)
AUTOCORRELATION FUNCTION (ACF), DIGESTED SLUDGE TOTAL SOLIDS RECORD, CHATHAM WPCP
95 % Confidence Limits
n = 122 Observations
Lag k (weeks)
PARTIAL AUTOCORRELATION FUNCTION (PACF) DIGESTED SLUDGE TOTAL SOLIDS RECORD, CHATHAM WPCP

FIGURE 5. WEEKLY DIGESTED SLUDGE SOLIDS CONCENTRATIONS, CHATHAM WPCP, 1973-1975 (Dashed Lines Indicate Missing Data)

weeks apart were correlated. Observations one or two weeks apart were highly correlated with $r_1 \approx 0.8$. Box and Jenkins (1970) discussed a process with an ACF almost identical to the ACF shown here. They indicated that such a series of observations was characterized by similarities in neighbouring values and exhibition of marked trends. Trends are readily apparent in the total solids record. More frequent sampling after the observation of a major deviation from the mean may help to characterize the digested sludge, and identify conditions such as excessive heavy metal concentrations. In the process industries, control charts with a variable describing product quality plotted in time have been used to monitor process outputs for quality control. The ease of their construction and use would make them amenable to on-site application by plant operating staff for monitoring sludge solids content. They might also be used to monitor changes in other constituent concentrations such as metals and nutrients, and clearly indicate changes not readily apparent from tabulated data. In a recent publication, Zickefoose and Evans (1976) described the use of control charts with moving averages to monitor trends in the anaerobic digestion process.

The total solids record from July, 1973 to November, 1975 and the ACF were used to estimate an optimum sampling frequency. The ACF (Figure 5) indicated that observations about four weeks apart were not correlated. Bendat and Piersol (1966) suggested that the sampling frequency should be about twice the rate of occurrence of uncorrelated observations. The sampling frequency for the digested sludge total solids should be once every two weeks at this plant. Bendat and Piersol stated that sampling times too close together can yield correlated and redundant data, and give little increase in information for the additional cost. The plotted data (Figure 5) indicate that a two-week sampling frequency should adequately reveal the long term variations in the data. Knowledge of within-day variability must be used, however, to ensure representative sampling; operating experience should provide this information in a manner similar to that discussed above.

The supplementary sampling survey for heavy metals and nutrients provided insight into long term variations. The data were generated by compositing three grab samples collected within each day. Figure 6

shows the main features of the constituent records. Many of the comments about the variations in total solids concentrations can also be made for the chemical constituents; nevertheless, there are significant, additional observations. These include:

1. a decrease in NH_3-N during the study;
2. peaks in total solids and TKN concentrations during September and October (attributed to seasonal food processing industry);
3. peaks in Cu and Zn concentrations during July and August;
4. a steady increase in Zn concentration from mid-September onwards; and
5. a lack of correlation between heavy metals and total solids during the long term period.

Regular monitoring of sludges is essential where input variations or process variations, or both, are significant. This is particularly true where solids and metals are not correlated, and their relationship cannot be used for prediction purposes. As indicated before, correlations may be useful during short term periods when solids and metal concentrations are related.

A survey at the Chatham WPCP was carried out simultaneously by an independent agency (MOE). One grab sample was collected each weekday; at the end of the week the five grab samples were combined to form a composite sample. This procedure was repeated every second week. Copper, nickel, and zinc determinations are plotted for these composites on Figure 6. Most of the sample points compare favourably with the data which were collected in the supplementary survey. With one exception for zinc during October, the independent samples and the supplementary survey samples did not differ more than might have been expected (cf. Table 4). The larger deviations do emphasize the need for well designed and consistent sampling strategies. To some extent, the deviations can be accounted for by the factors identified in the short term sampling surveys.

In summary, variability in liquid digested sludge, semi-continuously fed to a centrifuge, was assessed for short term (< one month) and long term (~ one year) periods. The importance of representative sampling within an operating day was emphasized to ensure reliable

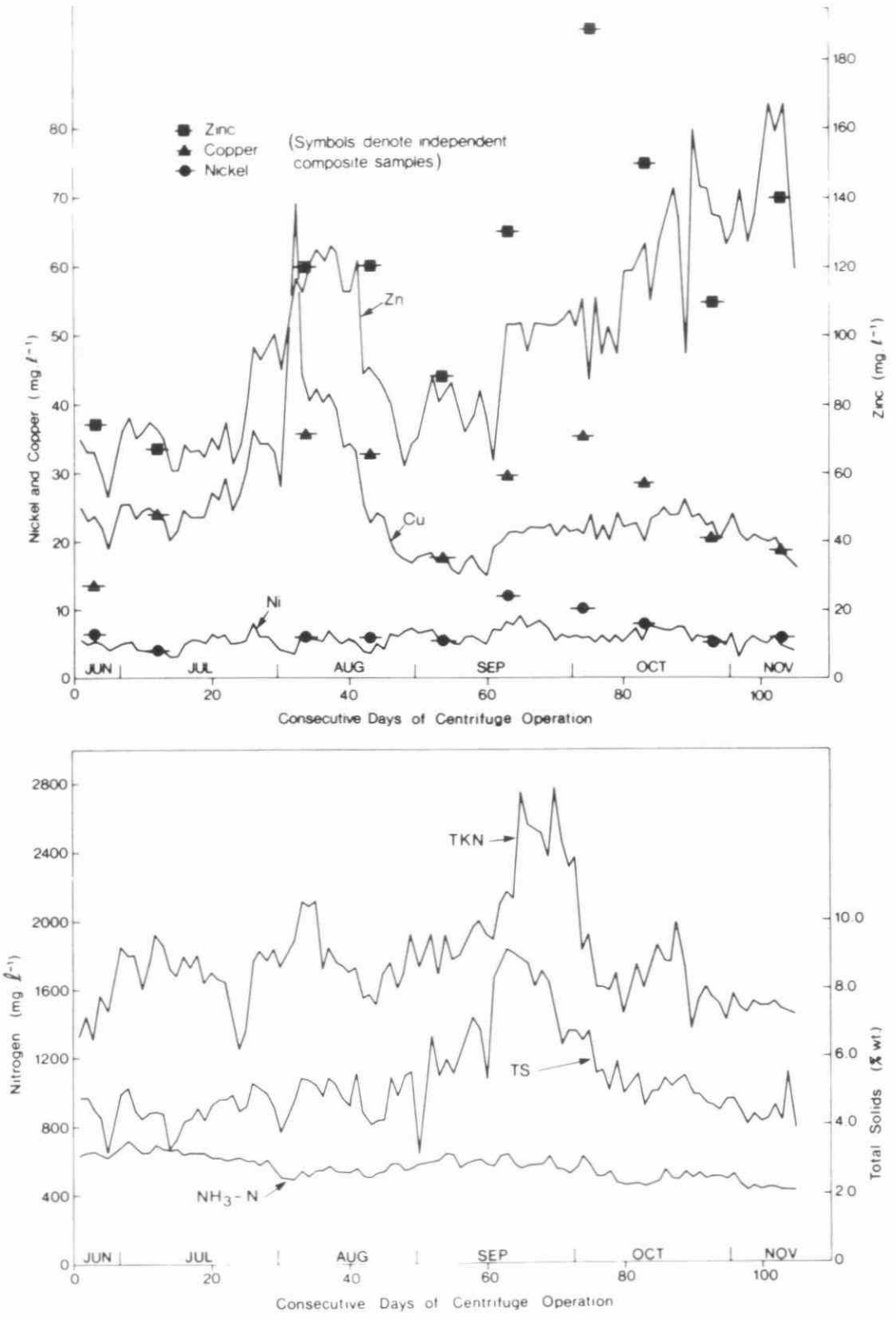

FIGURE 6. VARIATION OF PARAMETER CONCENTRATIONS CHATHAM WPCP, JUNE 23 TO NOVEMBER 14, 1975

samples collected through an operating day, should be obtained to account for the decrease in solid phase constituent concentrations.

Oakville S.E. WPCP (Batch Mode)

The large amount of data collected for the Oakville S.E. plant was systematically reduced to permit its interpretation. The constituent means of the first, second, and third samples within batches, for all batches and all days, were calculated from the raw data, and were plotted in order of occurrence (Figure 7). On the average, there was a steady decrease in constituent concentrations associated with the solid phase as sludge was discharged to a tank truck. Little variation was observed between NH_3-N determinations in the sample sequence. The decrease in solids may be expected because of the accumulation of more dense solids at the bottom of the unmixed, secondary digester; because of the creation of a draw-down cone; or because of channeling through the sludge blanket.

Mean constituent concentrations for batches within days are plotted in Figure 8. Again, solid phase constituents decreased in a sequence of batches discharged within the same day. At this plant, batches one, two, and three were withdrawn from the same sump in the digester, and they demonstrated a steady decline in solid phase constituent concentrations. Total solids decreased by more than 25% between the first and third batches. On the average, the plant operator altered the sludge pump suction to another sump after the third batch was processed; this resulted in a temporary increase in solid phase constituents in the fourth batch (Figure 8), but the characteristic decline was evident once again. Figures 7 and 8 show that the decrease of solid phase constituent concentrations corresponded with the withdrawal order. The variations between batch loads of sludge may be great enough to cause concern with regard to process monitoring. The figures represent average conditions; within some days the variations were more pronounced.

Mean constituent concentrations between the study days are plotted in Figure 9. The most striking features in Figure 9 are the trends exhibited by the mean daily total solids and zinc concentrations; these constituents increased until the seventh sampling day. No trends were evident for TKN or NH_3-N concentrations.

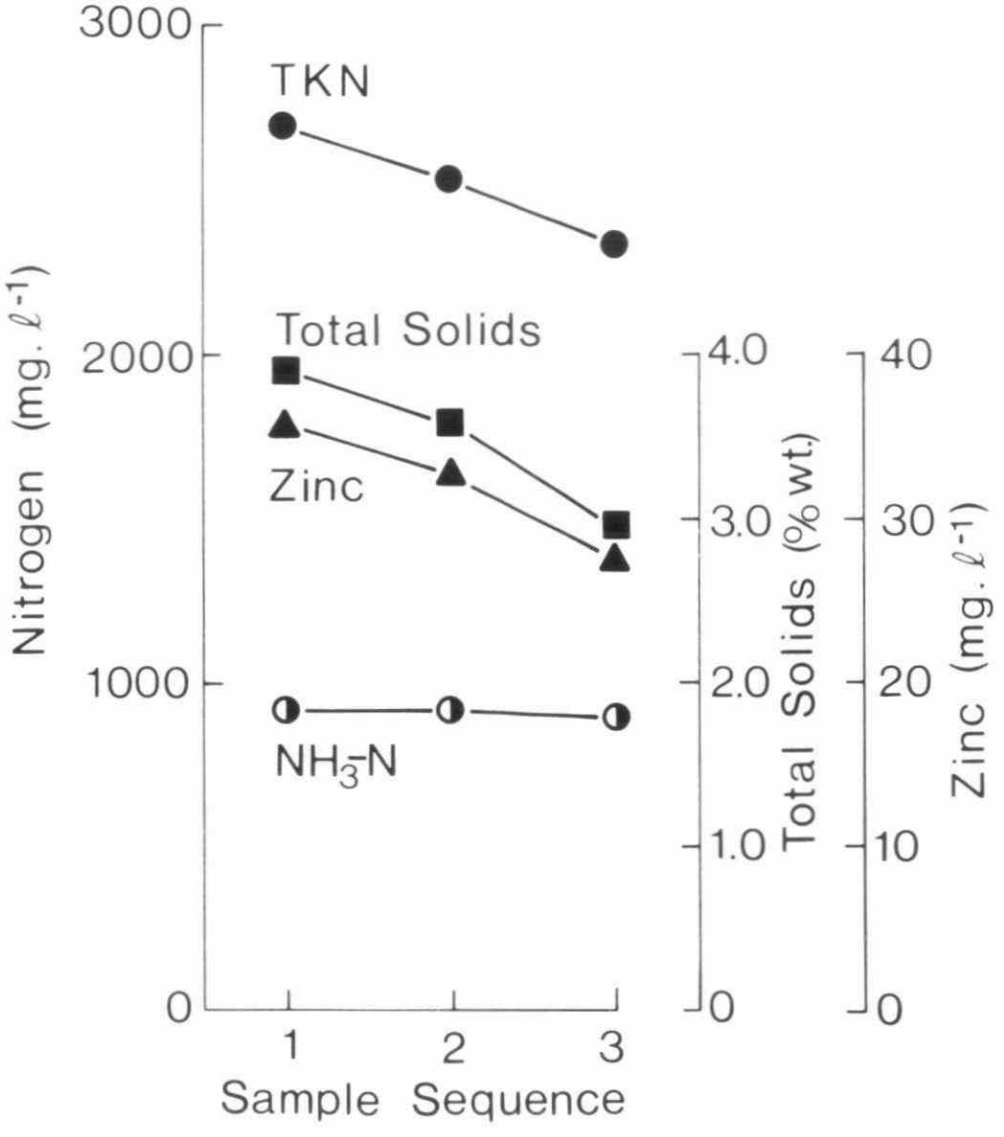

FIGURE 7. MEAN PARAMETER CONCENTRATIONS BETWEEN SAMPLES WITHIN BATCHES, OAKVILLE S.E. WPCP

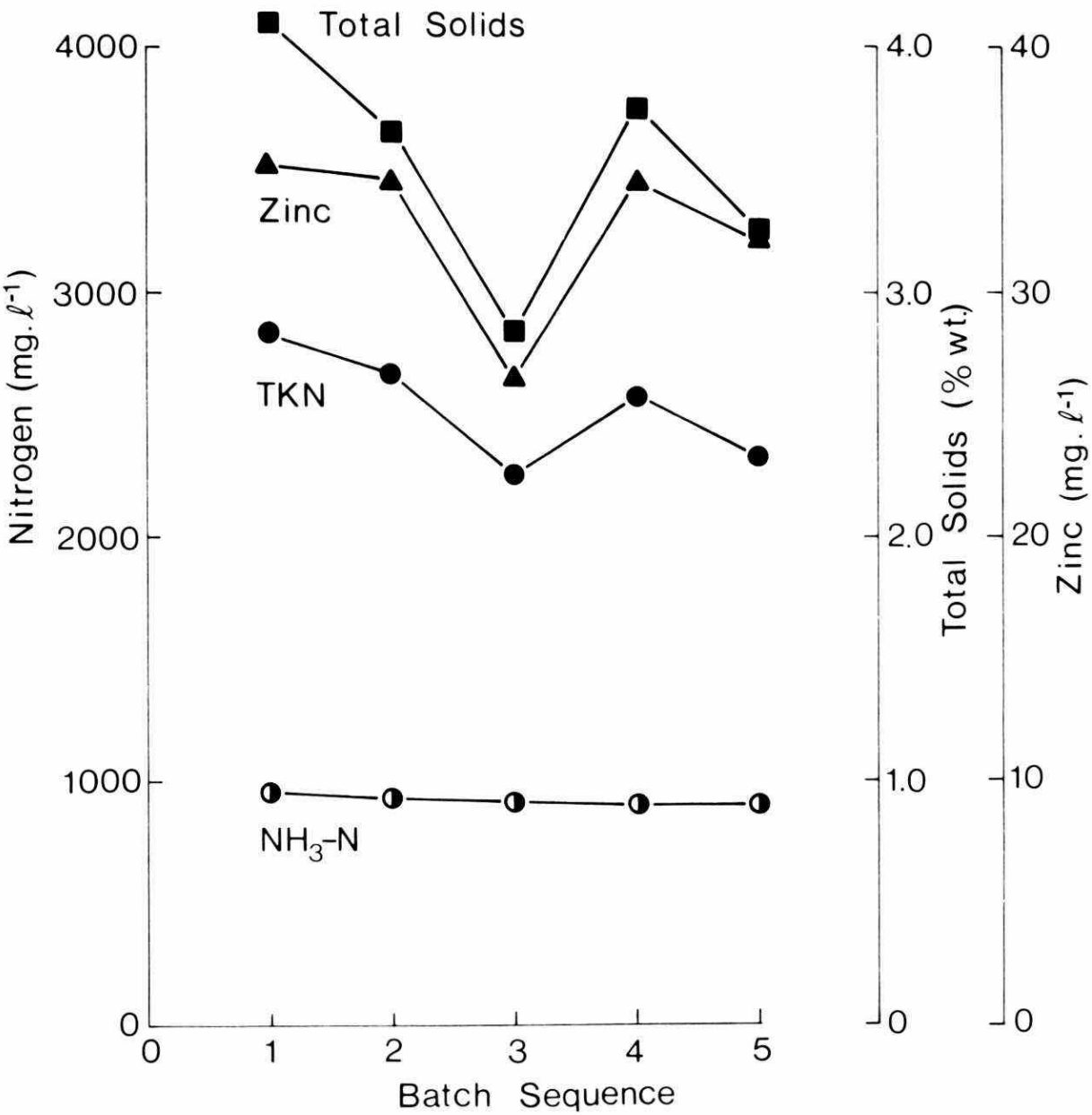

FIGURE 8. MEAN PARAMETER CONCENTRATIONS BETWEEN BATCHES WITHIN DAYS, OAKVILLE S.E. WPCP

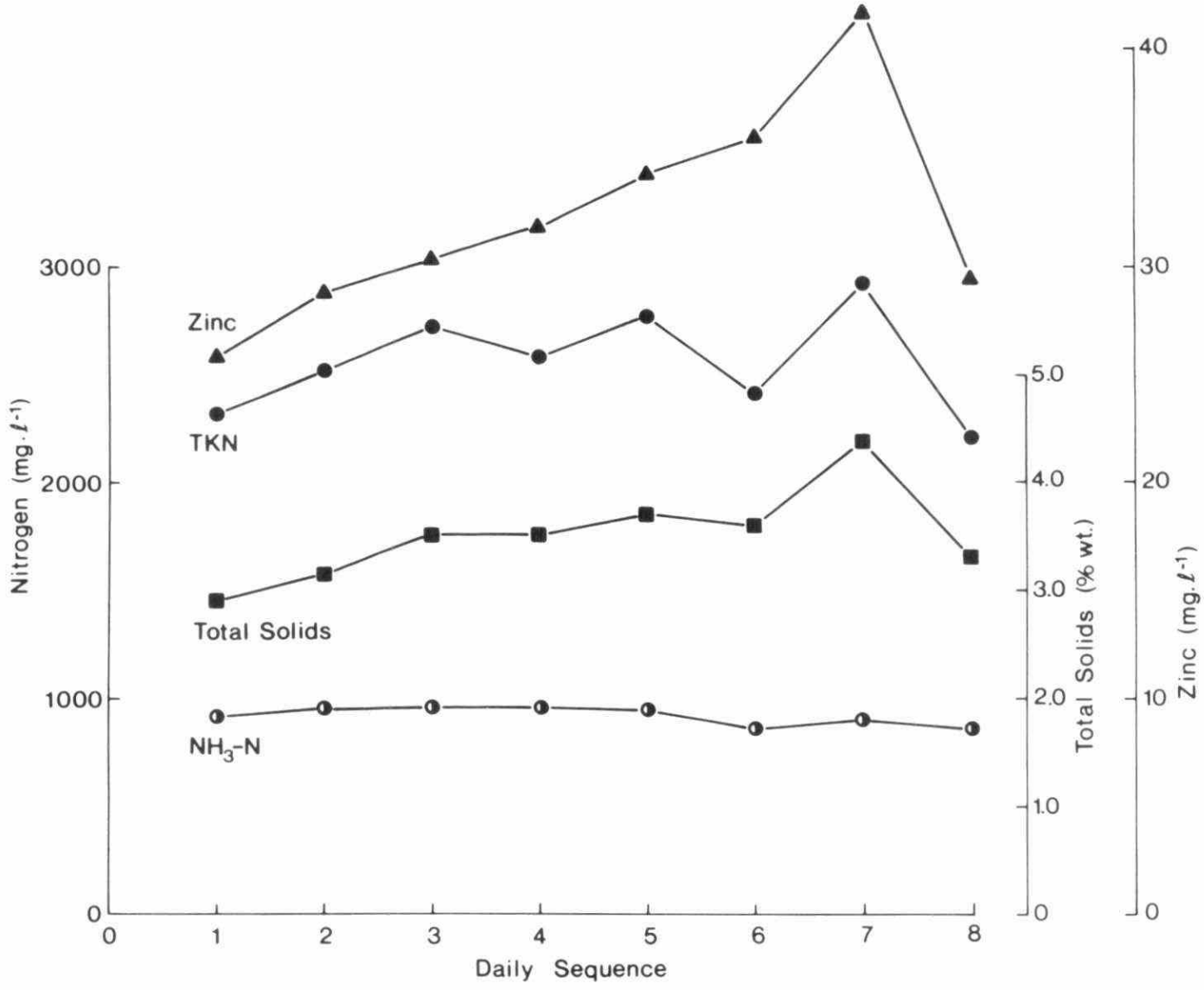

FIGURE 9. MEAN PARAMETER CONCENTRATIONS BETWEEN DAYS, OAKVILLE S.E. WPCP

Based on the ANOVA (Table 5), the data suggest that variations between days are a result of variations already present within sampling days; daily mean constituent concentrations are less variable than between batch or within batch variations. Inspection of the components of variance, s^2, clearly indicates the important sources of constituent variability. A good sampling plan will take these sources into account: most effort should be spent obtaining a representative sample for each batch within a day, and less effort should be directed towards sampling between days. At this plant, variations between the days during the nine-week sampling period were less than the variability between days or between weeks at the Chatham WPCP, and the sampling frequency might safely be reduced. Long term data were not available for this plant, and an optimum sampling frequency could not be determined using a time series approach. The reduced variability may be a result of the low loading rate to the system (Table 1), and the relatively uniform characteristics of the domestic wastewater being treated. Trends between the days were not taken into account by the ANOVA, but were probably real effects, and should be monitored carefully. A sampling frequency of one day every two weeks is recommended for this purpose.

The within-batch constituent RSD's (Table 3) were significantly greater than the within-day RSD's calculated for the Chatham WPCP where sludge was dewatered. Analysis of the Oakville S.E. data has shown that more effort would have to be expended to characterize sludge discharged batchwise than to characterize sludge discharged semi-continuously with the same precision (Table 4). A very large number of samples (Table 3 and Figure 1 indicate about ten samples) would be required to predict solid phase constituent concentrations in a single batch of sludge with precision of even $\pm$25% of the mean. The calculated RSD's and precisions represent upper bounds, since systematic sampling can partly account for the decreasing trends shown in Figures 7 and 8.

SUMMARY AND CONCLUSIONS

The greatest contribution to digested sludge variability occurred within a single operating day irrespective of the type of discharge method (batch or semi-continuous). Variability between days was masked by variability within days during two or three week periods.

TABLE 5. ANALYSIS OF VARIANCE, OAKVILLE S.E. SLUDGE

Source of Variation	df	Total Solids			TKN		
		Mean Square	Significance	$s^2(\%)^2$	Mean Square	Significance	$s^2(mg \cdot l^{-1})^2$
Between daily periods	7	4.64004	NS	0.0	1,256,260	NS	7,770
Between batches within days	25	6.73660	**	0.9841	1,046,540	**	149,820
Between samples within batches	66	2.26996	**	1.4225	369,760	**	186,940
Between repeats within samples	48	0.22156		0.2216	100,570		100,570

Source of Variation	df	NH_3-N			Zinc		
		Mean Square	Significance	$s^2(mg \cdot l^{-1})^2$	Mean Square	Significance	$s^2(mg \cdot l^{-1})^2$
Between daily periods	7	15,745.7	NS	0.0	558.48	NS	0.0
Between batches within days	25	19,828.9	**	3,558.1	570.35	**	77.44
Between samples within batches	66	3,996.5	**	2,252.6	217.53	**	123.68
Between repeats within samples	48	752.8		752.8	39.43		39.43

* Significant at 95% level.
** Significant at 99% level.
NS Not significant at 95% level.

As shown by the difference between a plant where sludge was withdrawn batchwise and a plant where sludge was withdrawn semi-continuously, increasing variability resulted from increasing rates of sludge withdrawal. Liquid phase constituents, however, were significantly less variable than solids phase constituents for both sludge discharge methods.

Since within-day variability is highly significant, it is important to obtain a representative sample during a sampling day. Where sludge is discharged semi-continuously, it is recommended that a composite sample, composed of at least three grab samples collected through an operating day, be obtained for effective sludge characterization. Constituent concentrations on non-sampling days should be estimated from concentrations measured on the nearest sampling day. Analysis of long term records from one plant, where significant system responses were obtained and where mixing studies were performed to characterize detention times (Monteith and Stephenson, 1978), indicated that a two-week sampling frequency (i.e., one sampling day every two weeks) was adequate to account for long term variations.

Where sludge is discharged batchwise, it is clear that batches of sludge must be sampled and analyzed separately on a sampling day for effective characterization. At least three grab samples should be systematically collected and composited for each batch load. Constituent concentrations in batches discharged on a non-sampling day should be estimated by results from corresponding batches on the nearest sampling day. A frequency of one sampling day every two weeks should be adequate to account for long term variations.

Table 6 summarizes the digested sludge sampling recommendations which have been formulated from this study, and gives a side-by-side comparison for batch and semi-continuous modes of sludge withdrawal. Also, Figure 1, Table 3, and a two-week sampling frequency have been used to re-evaluate the sample collection procedures necessary to obtain an arbitrarily stipulated precision ($\pm$25%) in mean total solids concentration for both withdrawal modes; the results are given in Table 6. This re-evaluation clearly shows the greater effort required to characterize

TABLE 6. SUMMARY OF SAMPLING PLANS FOR CHARACTERIZATION OF DIGESTED SLUDGES

WPCP Type	Sampling Frequency	Sample Collection	Precision* (±%)			
			Total Solids	Zinc	TKN	NH_3-N
Semi-Continuous Mode	1 day / 14 days	3 grab samples composited to make one sample	16	16	13	5
	1 day / 14 days	2 grab samples composited to make one sample**	25	25	20	7
Batch Mode	1 day / 14 days	3 grab samples per batch composited to make one sample; each batch sampled separately	43	46	27	7
	1 day / 14 days	9 grab samples per batch composited to make one sample; each batch sampled separately	25	27	15	4

* Precisions estimated at 95% confidence level.
** Nearest whole number of samples required to obtain stipulated precision.

sludges from batch mode plants with a precision equivalent to that obtainable at semi-continuous mode plants, and demonstrates the flexibility which can be obtained in a sampling scheme by using Figure 1.

A well founded sampling strategy is essential to characterize process streams efficiently. The plans described here provide a sound basis for sampling plans to characterize digested sludges as they are currently processed.

NOMENCLATURE

ACF	-	autocorrelation function
ANOVA	-	analysis of variance
MIGD	-	million gallons per day (Imperial)
MOE	-	Ontario Ministry of the Environment
NH_3-N	-	ammonia, expressed as nitrogen
PACF	-	partial autocorrelation function
RSD	-	relative standard deviation
TDS	-	total dissolved solids
TKN	-	total Kjeldahl nitrogen
TS	-	total solids
WPCP	-	water pollution control plant
df	-	degrees of freedom
n	-	sample size, number of samples
r_k	-	autocorrelation coefficient
s	-	sample standard deviation
$\bar{x}$	-	sample mean
$\hat{\phi}_{kk}$	-	phi, partial autocorrelation coefficient

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VIRUSES AND PARASITES IN SEWAGE SLUDGE

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INTRODUCTION

The survival of pathogenic microorganisms in sewage sludge is very important in the consideration of any sludge utilization guidelines. The use of the sludge should not create conditions under which surviving microorganisms become a hazard to public health; this could occur in three main ways:

a) The contamination of ground and surface water supplies adjacent to the area of sludge use.

b) The transmission of diseases to man or animals having access to the sludged land.

c) The carrying of infection to man or animals by fruit, vegetables or other crops grown on land fertilized by sewage sludge.

In parasites and viruses are represented some of the most resistant pathogenic microorganisms known. An outline of the properties and characteristics of those of importance in sewage and sludge will be given, along with some of the results obtained from two Canada-Ontario Agreement (COA) studies. These studies investigated their occurrence and survival in sewage sludges, both under laboratory conditions and after spreading on agricultural land.

VIRUSES

Viruses are simply composed of aggregates of nucleoprotein, either ribonucleic acid (RNA) or deoxyribonucleic acid (DNA), surrounded by a protein coat of geometric structure (Figure 1) [1]. Sometimes, a further covering or capsule is present. They are very small, their measurements being in the millimicron range, and they will pass through filters that could withold bacteria.

They can multiply and grow only within living cells; thus after being shed from an infected host, the virus becomes essentially dormant, with the potential of reproduction only upon contact with a suitable

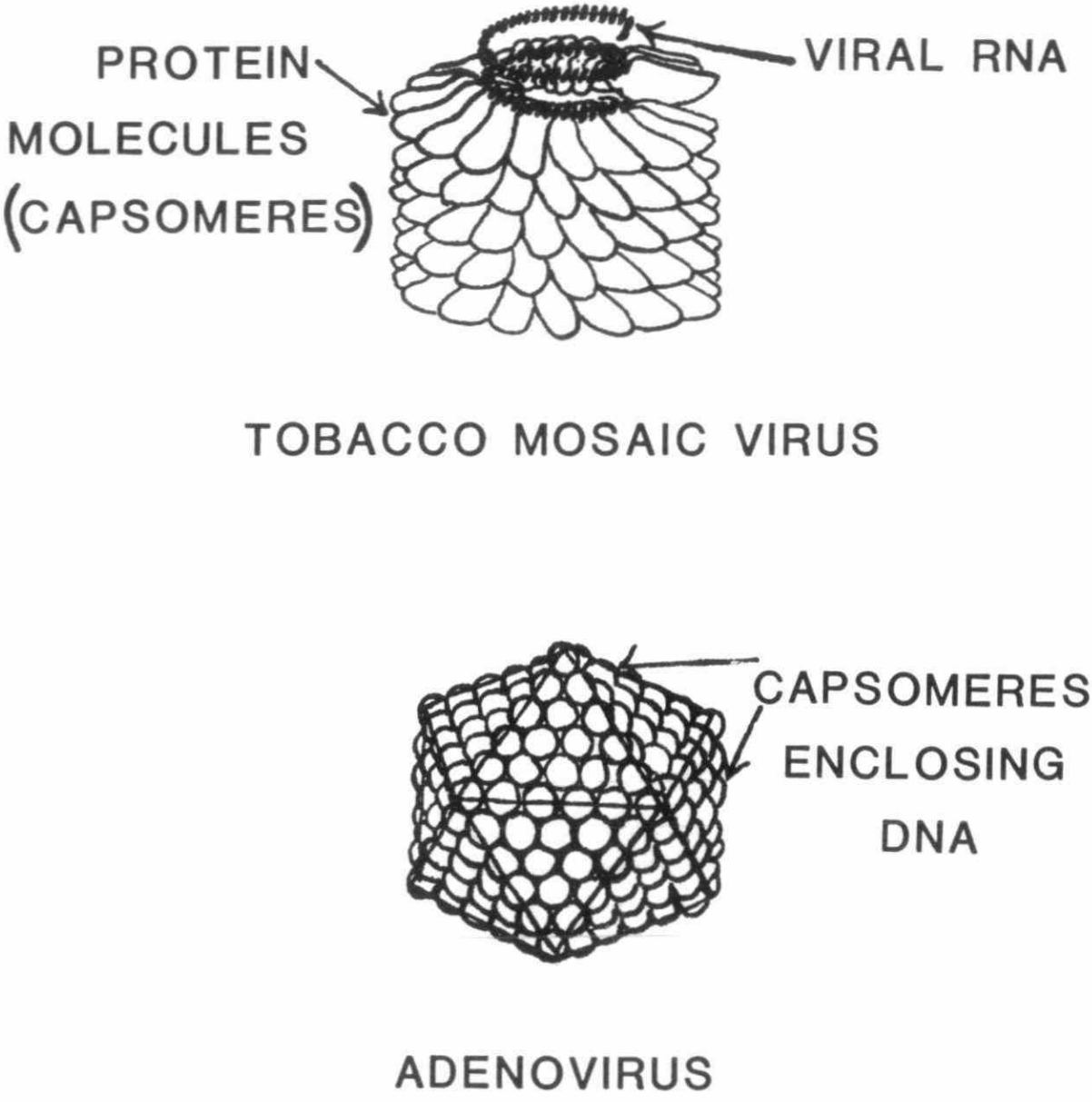

FIGURE 1. VIRUS STRUCTURE

Above, a rod-like particle of tabacco mosaic virus, with capsomeres attached to viral RNA surrounding a hollow core. Below, an adenovirus particle with the capsomeres arranged with icosahedral symetry around viral DNA.

living cell. This means that they cannot multiply in the environment, e.g. in sewage, surface water etc., which in part, accounts for the low numbers of viruses in environmental samples and the consequent difficulties with their isolation. However, since a single virus is potentially capable of causing an infection in a susceptible host [2], low numbers can still cause a significant public health hazard. Most viruses are spread by direct person to person transmission by contact or droplet inhalation. The group known as 'enteric viruses', however, multiply in the intestinal tract of the infected person, are shed in the feces and are present in sewage, sewage sludge and sewage polluted water. The major groups of the enteric viruses are shown in Table 1 [3]. These viruses can also be transmitted directly from person to person and, in fact, infectious hepatitis is the only virus for which waterborne transmission has been proved; it still cannot be isolated in the laboratory.

TABLE 1. HUMAN ENTERIC VIRUSES AND DISEASES

Sub Group	Number of Types	Disease
Infectious hepatitis	1 (?)	Infective hepatitis
Coxsackie virus: Group A	25	Herpangina, aseptic meningitis
Group B	6	Pleurodynia, aseptic meningitis
Poliovirus	3	Paralytic and non-paralytic polio
Echovirus	32	Aseptic meningitis; diarrhoea and rash
Adenovirus	28	Respiratory and eye infections
Reovirus	3	Respiratory, gastrointestinal upset and rash

The enteric viruses are circulating in the community all the time, particularly among children [4], and their numbers in sewage will depend on the level of infection in the population. In most of North America, the highest numbers are found in late summer and fall, as shown in Table 2 [5,6,7]. These same types would be expected to occur in raw sludge, since viruses in general are highly resistant and tend to be

TABLE 2. VIRUS ISOLATES IN SECONDARY EFFLUENT, FLUSHING MEADOWS, ARIZONA

Sampling Dates	Viruses per 100 L	Type of Virus
January	786	Polio 2, Echo 15
March	2745	Polio 2, Echo 7
May	2378	Polio 2 and 3
June/July	158	Polio 2, Coxsackie B_4
August/September	7475	Reovirus 1 and 2
November/December	1142	Reovirus

associated with particulate material [8]; this would be especially so in sludges produced during phosphate precipitation processes, since chemical precipitation is a method used for virus concentration and purification [9].

It has been shown [10], that viruses can migrate through soil; the migration is greater in sandy soils and may be especially pronounced after heavy rainfall. However, intermittent applications of waste may result in highly efficient adsorption of viruses to the soil [11]. If enteric viruses gain access to a water source, they can survive for weeks or months, depending on the conditions [12].

The COA studies carried out by Dr. Subrahmanyan [13] at Ontario pollution control plants where phosphate removal was in progress, indicated that about 16% of digested sludges were positive for enteroviruses when 100 ml quantities of sludge were tested. The method of isolation used was estimated to be capable of recovering 30 to 50% of the virus present in the sludge. In laboratory studies, with artifically seeded sludges, virus survival was shown to be greater at 4°C than at 22°C, as shown in Table 3. Further such experiments revealed that most viruses were reduced to undetectable levels after 12 weeks at 22°C, even though they were seeded with virus levels much higher than those found in normal digested sludge. During the summer months under dry and sunny conditions, temperatures at the soil surface or just below (1" depth), have been measured at 30°C or above, and can reach as much as 40°C for extended periods (H.J. Graham, personal communication); virus inactivation would be expected to be much more rapid at such temperatures.

TABLE 3. POLIOVIRUS SURVIVAL IN SLUDGE

Day	Number of Virus Added	Number of $TCID_{50}$ detected at 4°C	22°C
0	200 $TCID_{50}$	-	56
2		56	100
3		56	56
7		56	56
14		32	10

Human enteric viruses appear to be species specific and would create little hazard to farm animals, should sludge be used on pasture; they could conceivably survive on the surfaces of vegetables grown on sludged land, but the time required for the maturation of the crops would probably be sufficient for virus inactivation. Therefore, given certain safeguards, such as minimum distances from wells and water courses, restriction of immediate access and some limitation of fruit and vegetable crop growth, there appears to be little public health hazard from viruses associated with spreading digested sludge on agricultural land.

PARASITES

Parasites are a diverse group of organisms, one group of which is adapted to growth within a human or animal host; infection with a parasite rarely leads to death (although severe side reactions can occur), and in many cases may be without symptoms. Some parasites require the presence of an intermediate host during their life cycle and some do not; as with the viruses, actual multiplication of the parasite only occurs within a host.

The parasites of concern, with man as the primary host, in sewage and sludge are shown in Table 4. All have the property of producing, at some time during their life cycle, an ovum or cyst that is extremely resistant to environmental conditions; these resistant forms are generally shed in the feces of the host organism. As with the viruses, parasitic infections can be found in any community at all times, and the ova and cysts can be found in all domestic sewage and sludges [14]. Since the soil, even when of a sandy composition, would act as an efficient filter for the cysts and ova

TABLE 4. PARASITES OF CONCERN IN SEWAGE SLUDGE

Name	Intermediate Host
1) Helminths	
Nematodes - Roundworms	
Ascaris lumbricoides	None
Trichuris trichiura	None
Cestodes - Tapeworms	
Taenia saginata	Cattle
Taenia solium	Pigs
2) Protozoa	
Entamoeba histolytica	None

the potential for contamination of groundwater is felt to be minimal; surface water contamination by runoff remains a possibility in the absence of adequate safeguards.

Of the protozoal group, Entamoeba histolytica is the most important, and it is the cause of amoebic dysentery. Cysts are shed in the feces of infected individuals, which if ingested by man develop in the intestine to cause the infection. The cysts of Entamoeba are considerably less resistant than those of the other parasites [18] and their persistence in sludge and on soil is thought to be relatively short.

Considering the life cycle of the Taenia species, Figure 2 [15], the eggs are shed in the feces of the infected primary host (man); they will survive sewage treatment processes, including sludge digestion [16], and remain viable for considerable periods in the sludge. Longer survival times prevail under cool, damp conditions than under hot, dry ones [17]. Upon ingestion by a ruminant (cattle) in the case of T. saginata or a pig in the case of T. solium, the larvae migrate to the blood stream and are carried to various locations in the body and develop into cysticerci; meat infested with these is termed "measly". Man becomes infected by eating undercooked, infected meat, since the cysticerci develop into adult tape-worms in the intestine.

If farm animals are allowed access to sludged land or water sources harboring surviving Taenia ova, they may become infected. Although man may

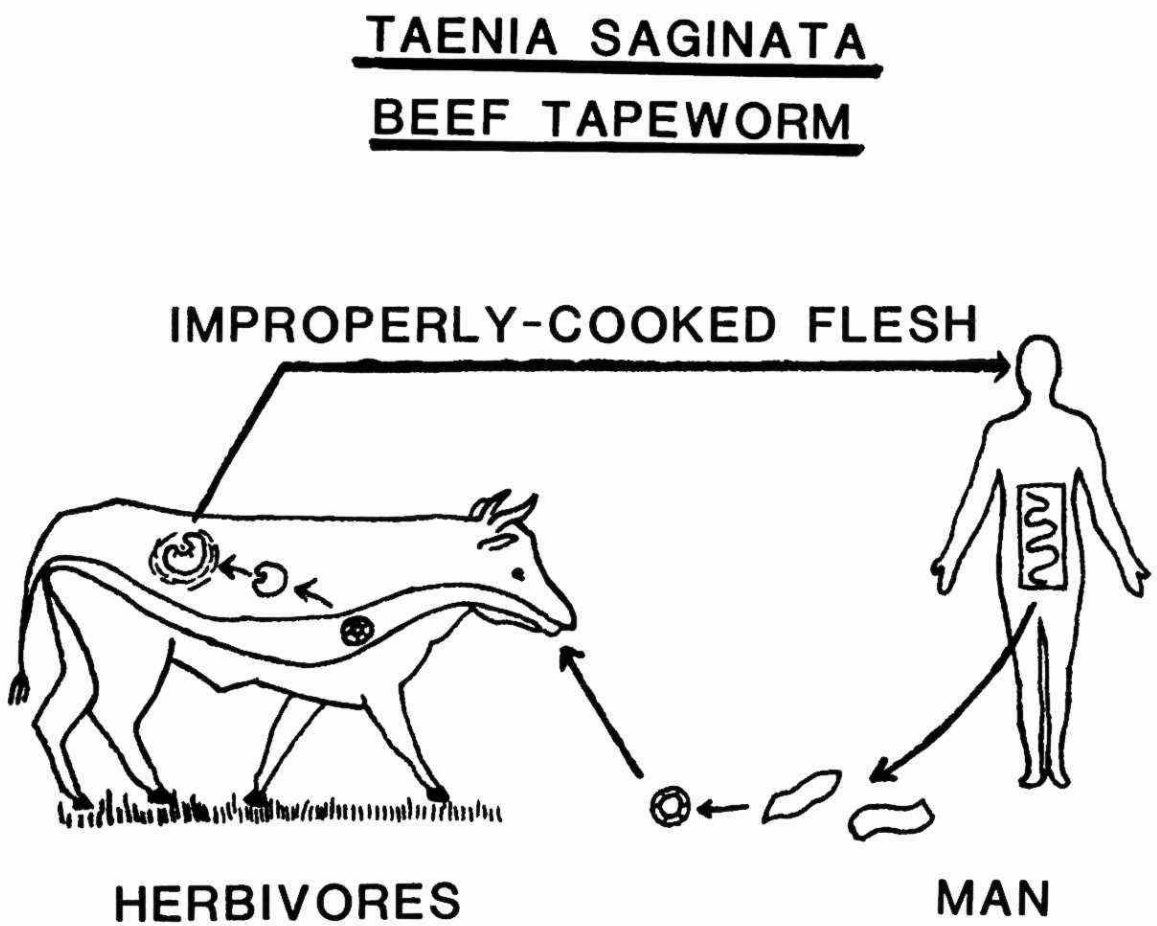

FIGURE 2. THE LIFE CYCLE OF THE BEEF TAPEWORM, T. SAGINATA; MAN IS THE PRIMARY HOST

be protected, because the affected meat should be condemned at slaughter, the consequent economic loss to the farmer could be considerable.

The life cycle of Ascaris species is similar to that of Trichuris species in that no intermediate host is involved. The ova are shed by infected persons, survive sewage treatment and sludge digestion and remain viable for considerable periods. In Trichuris (Figure 3) [15], the ova mature in three to five weeks in the soil and, upon ingestion, develop over a three-month period into adult worms in the human intestine. The development of Ascaris (Figure 4) [15] is more complex. After maturation in the soil, ingested infective ova develop into larvae which penetrate the intestinal wall and are carried to the lungs; in the alveoli further development occurs (causing pneumonitis in the lung) after which the mature larvae are coughed up and swallowed, to complete development in the intestine. The maturation process in man may take several months. Man becomes infected by both types upon ingesting food or water contaminated with the infected soil.

Since man is the only host required for the propagation of these two parasites, farm animals would not be at risk on pasture infected with ova from these organisms; however, the possibility of the direct transmission of ova to man on vegetables or fruit grown in sludged soil is obvious.

Little specific has been reported here regarding the longevity of Nematode and Cestode ova, because there is little agreement in the literature; estimates of survival range from few weeks to several years [18].

Mr. Hugh Graham (H.J. Graham, personal communication) is conducting a COA study involving the isolation of parasitic ova and cysts in Ontario sewage sludges, and is currently assessing their potential for survival under the climatic conditions of Southern Ontario.

Thus far, Trichuris and Ascaris eggs have been isolated with regularity, in amounts ranging from 20 - 40 per litre, and 20-280 per litre, respectively, after sludge digestion, and they <u>appear</u> to be viable; however, it could be that their ability to infect an individual has been impaired [19]. Very few Taenia eggs have been found, corresponding with

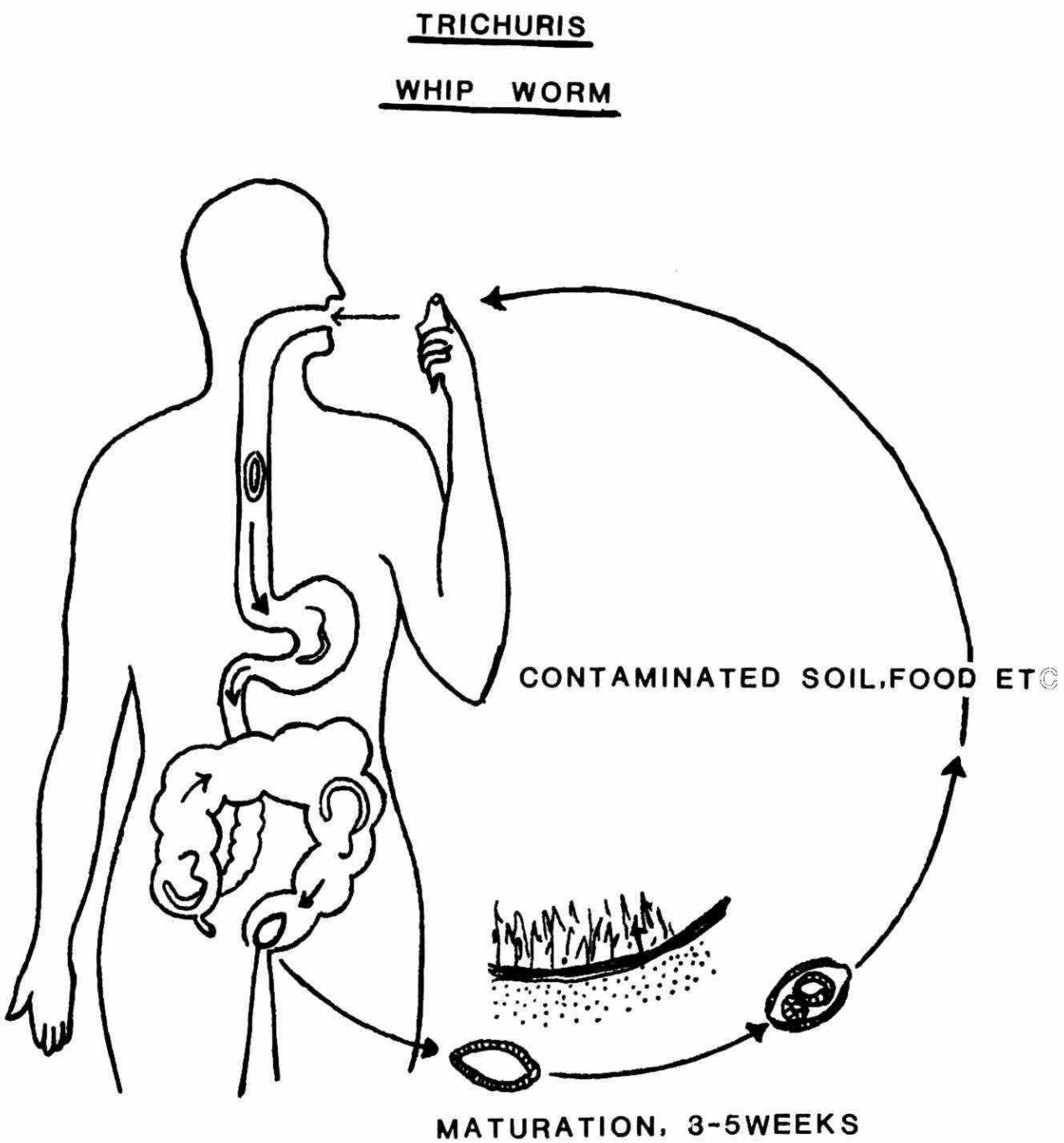

FIGURE 3. THE LIFE CYCLE OF TRICHURIS TRICHIURA, THE WHIPWORM; MAN IS THE ONLY HOST.

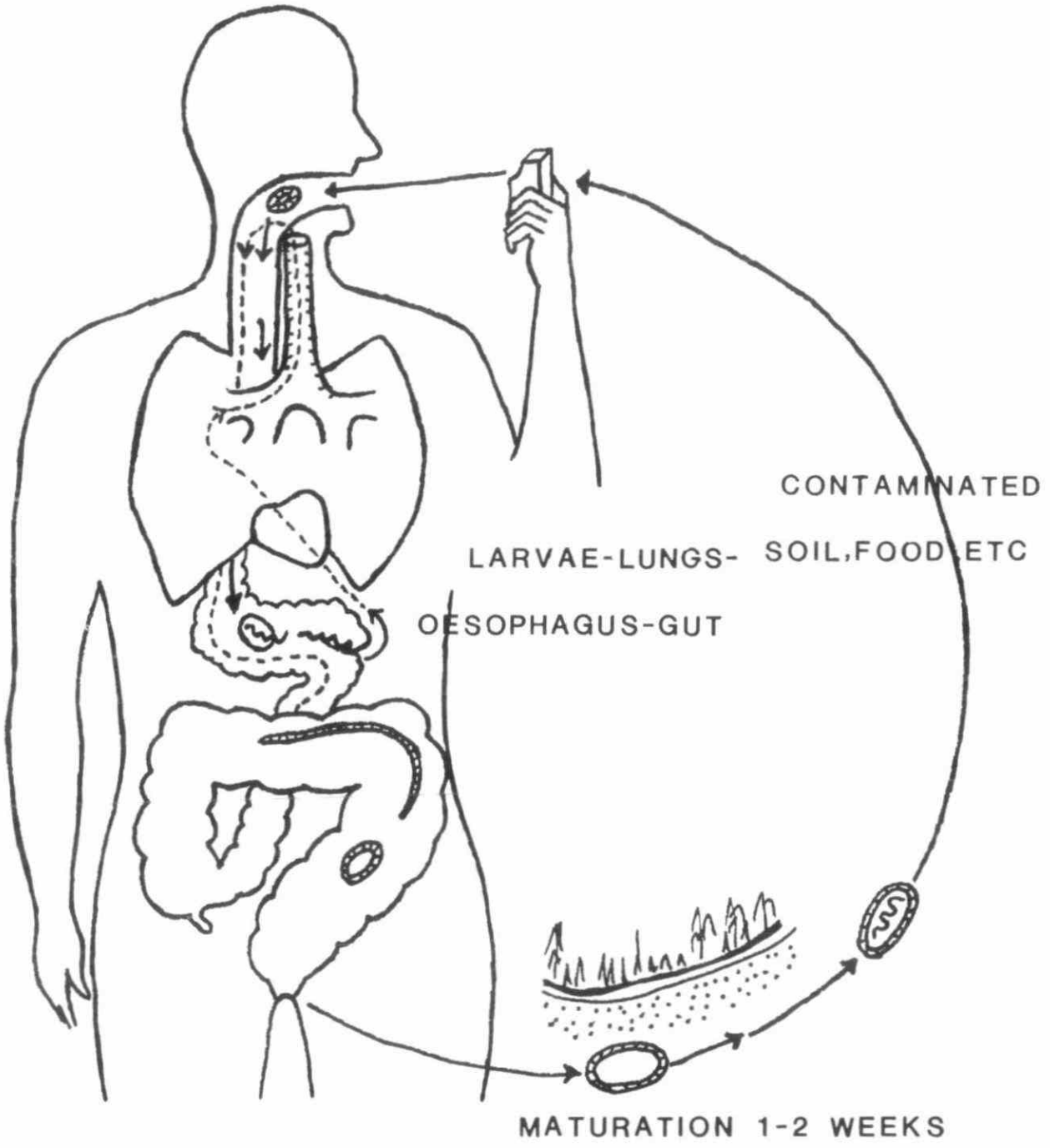

FIGURE 4. THE LIFE CYCLE OF THE ROUND WORM, ASCARIS LUMBRICOIDES; MAN IS THE ONLY HOST

a very low incidence of detected Taenia infections in the population of Ontario (Th. Scholten, Ontario Ministry of Health, personal communication), and isolation of amoebic cysts has not been attempted due to the difficulty in differentiating free-living amoebas from the pathogenic types. It has been determined that it is extremely difficult to detect parasitic ova and cysts once the sludge has been spread on land, even after artifical seeding of the sludge to much higher levels than those normally found. Final conclusions have not yet been reached, but it is felt that if the crop to be fertilized is to be used for human consumption, plowing under the sludge before planting would reduce the number of ova on the soil surface to a nonhazardous level.

SUMMARY

Both viruses and parasitic ova and cysts can survive sewage treatment and sludge digestion; once deposited in the environment they are capable of surviving for relatively long periods in an infective state if the conditions are suitable. Disposal guidelines are designed to minimize the health hazard to man and animals which may arise from the presence of these microorganisms. Past experience in Canada has indicated that there is, in fact, very little risk to either human or animal health, since no cases of infection have ever been associated with agricultural use of digested sewage sludge.

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METALS IN MUNICIPAL WASTEWATERS - SOURCES, LEVELS AND CONTROLS

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INTRODUCTION

Since its inception over one-hundred years ago, the Ontario mineral industry has produced, as a waste product, millions of tons of mineral tailings. These tailings are stored in individual areas that are scattered across the province. In many cases, the tailings disposal sites in question generate severe environmental problems. Reclamation of these areas tends to minimize environmental hazards but revegetation (a widely used reclamation procedure) of the often sterile wastes is, at best, difficult and expensive.

It has been suggested that the application of sewage sludge to the surface or surface layers of abandoned mineral tailings areas may enhance the prospects for the stabilization of these areas. Indeed, where this has been tried, the experiments have been largely successful. By adding a municipal waste to an industrial waste a medium is produced that will support the growth of vegetation. The vegetation solves a major industrial problem and the use of the sewage sludge solves a major municipal problem. However, as might be expected, things are not quite so simple.

It has long been known that the metals removed by common sewage treatment processes are generally concentrated in any sewage sludge that may be produced. High metal levels in these sludges have given rise to concern about the use of such sludges on land for agricultural purposes because of potential problems involving metal toxicity to plants and animals and because of the possibility of contained toxic metals leaching from the sludges. Seen in perspective, these problems are extremely serious when applied to the reclamation possibilities of an abandoned mineral tailings area. To begin with, mineral tailings areas routinely contain abnormal concentrations of toxic metals that give rise to metal uptake problems in vegetation. The addition of another potential source of metals in an organic base might be deemed unwise unless it could be

proven that the metals being added were in a stable form and were largely unavailable for use by plants or animals. The most complicating factor, however, is the inherent acidity of many of the areas requiring reclamation techniques. Tailings masses exhibiting pH values below 3.0 are quite common. While acid surface layers are normally neutralized with lime or limestone as part of the revegetation technique, few surface layers tend to remain alkaline for great lengths of time under the constant influence of upward migrating acid salts. The possibility of metals leaching from sewage sludge under these circumstances is great.

Metal loss from sludge applied to very acid or very alkaline masses of mineral tailings is not the only sludge-related problem that has to be faced. Given the probable success of large-scale attempts to enhance the growth of vegetation of abandoned tailings areas by the judicious application of available sewage sludge, we face the reality that such procedures would also tend to be applied to inactive or abandoned portions of active tailings areas as part of the progressive rehabilitation programs that are currently being carried out by operating mining companies in this province. Runoff, contaminated with organics, from such areas could report to the recycle water intake on the property and hence gain access to the operating mill. Unfortunately, complex differential flotation circuits are notorious for their sensitivity to unexpected or unwanted organics.

As a result of all of the foregoing, we found it useful to begin a brief investigation into the chemical nature and stability of sewage sludge. In particular, we were very interested in determining the number of specific metals that we could expect to encounter in sludges that might be disposed of on derelict mining lands. Since the metals found in sewage sludges are predominantly derived from metals in sewage plant influents, we first turned to the investigation of these influents. Subsequently our program was expanded to include metals in influents, sludges and effluents. Funding, approximately $16,000, was received from the Technical Committee of the Canada-Ontario Agreement on Great Lakes Water Quality. As such, work on the project began in the late fall of 1975 and effectively terminated in February of 1977 with the production of a report entitled "Sources of Metals and Metal Levels in Municipal Wastewaters" (Canada-Ontario Agreement Research Report No. 80).

The contract for COA Project 75-1-43 specified that the following work was to be carried out:

(1) "Compile from the available sources an inventory of data on metals in municipal sewage (city, plant, dates, flows, metals), quantities (influent, effluent and sludge) and metal removal efficiency.

(2) "Compile from available literature an inventory of data on the industrial waste regulations and by-laws of Ontario communities.

(3) "Examine data from residential-industrial communities to establish metal type and concentration expected from industrial areas.

(4) "Examine data from residential communities to establish metal type and concentration expected from a residential area."

The report produced was divided into five sections:

- Inventory of Data - Metals in Municipal Sewage (taken from 1974 and 1975 records of the Ontario Ministry of the Environment)
- By-laws of Ontario Communities
- Metal Sources in Sanitary Effluents from Residential Areas
- Sources of Metals from Industrial Areas
- Project Analytical Results (1975-1976 Field Season).

The project analytical results are regarded as the most important section of the report. Here, for the first time, the specific metal content of a large number of Ontario sewage plant influents, sludges and effluents are recorded in detail. In addition, metal removal efficiencies are recorded, metal loadings are noted and so forth.

The analytical data is augmented by the data in the inventory.

In all, the report based its findings on analytical data from more than 70 Ontario sewage treatment facilities.

Briefly, some of the conclusions found in the report are as follows:

(1) The metal-related <u>average characteristics</u> of Ontario sewage plant <u>influents</u> were as follows:

Zn	1.12 mg/L	Li	.01 mg/L
Cu	.30 mg/L	Co	.01 mg/L
Ni	.11 mg/L	Hg	1.03 ppb
Pb	.17 mg/L	Sn	.58 mg/L
Cd	.02 mg/L	V	.01 mg/L
Cr	.97 mg/L	As	.005 mg/L
Al	3.80 mg/L	Ba	.18 mg/L
Mn	.15 mg/L	Sr	.52 mg/L
Fe	6.58 mg/L	Mo	.01 mg/L
Ca	93.65 mg/L	Ag	.01 mg/L
Mg	22.31 mg/L	Se	.003 mg/L
Ti	.15 mg/L		

(2) The metal-related <u>average characteristics</u> of Ontario sewage plant <u>effluents</u> were as follows:

Zn	.29 mg/L	Ti	.08 mg/L
Cu	.06 mg/L	Li	.01 mg/L
Ni	.05 mg/L	Co	.01 mg/L
Pb	.02 mg/L	Hg	.07 ppb
Cd	<.01 mg/L	Sn	.42 mg/L
Cr	.09 mg/L	V	.01 mg/L
Al	.47 mg/L	As	.001 mg/L
Mn	.05 mg/L	Ba	.02 mg/L
Fe	.83 mg/L	Sr	.42 mg/L
Ca	95.0 mg/L	Mo	.02 mg/L
Mg	22.0 mg/L	Ag	<.02 mg/L
		Se	.002 mg/L

(3) The overall <u>metal removal capabilities</u> of existing Ontario sewage treatment plants were as follows:

Zn	54 to 74%
Cu	49 to 80%
Ni	41 to 55%
Pb	46 to 88%
Cd	16 to 50% plus
Cr	54 to 91%

Al	69 to 88%
Mn	48 to 67%
Fe	68 to 87%
Ca	very little removal: approximately 7%
Mg	very little removal: approximately 5%
Ti	24 to 47%
Li	removal mechanism operating: estimate 12%
Co	removal mechanism possibly operating: no estimate
Hg	61 to 93%
Sn	28 to 40%
V	removal mechanism operating: estimate 20%
As	73 to 80%
Ba	62 to 89%
Sr	low removal efficiency: estimate 15 to 19%
Mo	removal mechanism operating: estimate 5%
Ag	removal mechanism operating: estimate 14%
Se	23 to 34%

(4) The metal removal efficiencies of specific treatment plant types were as follows:

NOTE: Removal efficiencies based on Zn, Cu, Cr and Fe (inclusive) only.

(a) lagoon type treatment plants: 35% (low estimate)
(b) primary treatment plants: 47%
(c) activated sludge plants: 76%

From our standpoint, however, one of the most important conclusions of the report was that:

> "The prime function of a sewage treatment plant is to prevent contaminants (including metals) from entering receiving watercourses in undesirable amounts or concentrations. At the present time, however, even the most modern plants account for only an estimated 76 percent of the metal load discharged to them. The remaining 24 percent escape the plants.
>
> Given the large number of sewage plants in operation, their usual proximity to areas of human habitation and high volume effluents normally encountered at these plants, it would appear

to be desirable to increase the metal removal capabilities of most current and all future plants. This can be done to some extent indirectly by increasing restrictions on industrial discharges to sanitary sewers. The resolution of the total problem, however, lies only at the sewage treatment plant itself."

Implicit in the above conclusion is the realization that, given a progressive upgrading of existing and new facilities to achieve superior metal control in municipal effluents, metal levels in sewage sludge will continue to increase and will peak at a minimum of approximately 20% above existing levels, assuming that the present influent: sludge volume ratios are maintained. This means that sludge available for use on agricultural or mining lands in the foreseeable future will contain increasing concentrations of various metals, not stable or decreasing concentrations.

There is a fairly widespread belief that the modification of existing and/or future sewage plant designs is not or may not be necessary in order to achieve acceptable metals control. Proponents of this approach state that metals control can be just as easily achieved upstream of the plant at the actual sources of the metals. However, as our report points out, this concept will find only limited application at the present time due to the effectiveness of current Ministry of the Environment programs. For instance:

(a) "Point-source (at the industry) treatment of industrial discharges in Ontario at the present time is the rule rather than the exception."

In other words, most companies that discharge wastes containing significant amounts of toxic metals are normally required to treat these wastes at the industrial plant site itself using the best available practicable technology. More often than not, the resulting treated wastes are then discharged to a natural watercourse, a storm sewer leading to a natural watercourse or to a field tile system, etc.

and

(b) "Most municipalities in the Province actually regulate industrial discharges to sanitary sewerage systems via sewer-use by-laws."

While many small metal users or producers do discharge directly to sanitary sewers, they are subject, in almost all cases, to sewer-use by-laws.

> "Sewer-use by-laws such as the one used by the Province of Ontario represent an effective way to control metal discharges to municipal sewers. Such by-laws, however, must be rigidly enforced to be effective. Frequent review of the permissible metal levels recommended by such by-laws is necessary in order to accurately reflect constantly changing attitudes and technology."

There is no doubt that the complete elimination of all industrial discharges to sanitary sewers would lower the metal concentrations in sewage plant influents, sludges and effluents. However, significant metal problems would still remain due to the metal content of modern day "domestic" sewage.

Waste discharges from residential areas differ significantly from waste discharges from industrial sources. In general, domestic discharges from individual residences may be categorized as low volume chemically complex effluents, whereas industrial sources tend to generate high volume waste flows that quite often incorporate a known and/or a limited chemical spectrum. Up to the present time, the chemical and physical complexity of effluent originating in residential areas has not been fully appreciated. In many cases, effluents from these areas present waste treatment problems that are more complex than industrial sources of equivalent volume. In fact, nearly every metal or chemical substance known or used by man may, at one time or another, appear in the effluents from residential areas. This is due, in part, to the great number of chemical products available to an individual or to a household for limited or long-term private use.

It is well known that certain products available commercially find standard use in most homes and contribute significantly to metal loadings in municipal sewers. Such products include soaps and detergents used for washing dishes and clothes, bath products, products related to personal hygiene, cosmetics, medicines and household cleaners.

Very few of us realize that everyday menial tasks such as brushing our teeth, shampooing our hair, washing our hands, removing cosmetics or having a bath or shower contribute to the metal-related problems that presently occur at sewage treatment plants. However, this unfortunately is very true. Toothpaste, for instance, nowadays commonly contains approximately 0.4% tin (stannous) fluoride. By rinsing our mouths as we brush our teeth, most of this tin reports to the sanitary sewers. Present levels of tin in municipal plant influents range from less than 0.20 mg/L to 3.5 mg/L with an average across the province of 0.58 mg/L. A single individual who is brushing his or her teeth cannot be considered as an important source of tin as far as a sewage treatment plant is concerned; but several thousand such individuals routinely brushing their teeth <u>are</u> a significant source.

Popular dandruff shampoos contain selenium compounds. When we wash our hair, these compounds are discharged to the sewerage system. When we bath or shower, residual amounts of deodorants (aluminum compounds) and various cosmetics (containing a variety of metals) go down the drain and so forth. Whether we are cleaning the sink, the silverware or old paint brushes, the resultant waste solutions usually go down the drain.

While all of the foregoing are more or less obvious sources of metals that end up in our sanitary sewers, there <u>are</u> less obvious sources. The human mouth is one such source. While the mouth is usually filled with teeth, the teeth are usually filled with metal. To be precise, silver amalgam is dentistry's most serviceable filling material. In metallurgical language, an amalgam is any alloy or mixture of metals one of which is mercury. Throughout the world, dentists probably use more silver amalgams than any other filling. Silver amalgam as used in dentistry is prepared from two basic substances. One is liquid metallic mercury while the other is a finely powered silver alloy containing small amounts of copper, tin and zinc.

The influents to all of the municipal plants studied in detail during our project contained mercury. Ranging from 0.08 to 9.8 parts per <u>billion</u> and arithmetically averaging 1.03 parts per billion, the presence of mercury in raw domestic sewage is not surprising. Most of us are

Silver Amalgam Composition (approximate)

		Before 1970	1970 onwards
Silver	powder	69%	65%
Tin		25%	29%
Copper		4.5%	4 to 30%
Zinc		0 to 1%	2%

Mercury is incorporated with the above at 45 to 50% by weight.

aware of the fact that dental fillings do not last forever. Properly placed, a silver amalgam filling has a lifetime of approximately 20 years. The average weight of such a filling is between 400 and 600 milligrams. Prior to 1963, an average adult might have 14 of these fillings in his or her teeth. However, due to practices such as fluoridation of water supplies, this figure has dropped by 60% since 1963. Even so, adults now living probably contribute approximately 3 grams of mercury to sanitary sewers over a period of 20 years as a result of simple abrasion or destruction of silver amalgam dental work. Again, this loss of mercury is insignificant on an individual level, but when multiplied by the total population being served by a sanitary sewer, it becomes a highly significant and normally uncontrollable metal discharge.

There are other factors that also determine the chemical complexity of the wastes that flow in a sanitary sewer. For instance, the sewer does not normally receive wastes from only private residences. Additional sources commonly include apartment complexes, restaurants, hotels, institutions such as hospitals, laboratories, car washes, coin laundries, warehouses, automobile garages, and large and small shopping complexes none of which are considered to be "industrial" sources in the strict sense of the word.

We have previously discussed the metal removal capabilities of existing Ontario treatment plants. It is necessary to note at this point that the removal efficiencies quoted for each metal may not reflect the efficiencies of individual treatment plants as much as they reflect the form in which a metal normally reports to the plants. Metals that are commonly found in a sewer in a finely divided but nevertheless solid form (for example, metal precipitates) will in most cases be removed by a

particular treatment plant more efficiently than the same metals in dissolved form.

The report "Sources of Metals and Metal Levels in Municipal Wastewaters" is not confined to a discussion of metals. In fact, 40 parameters were used to describe the chemical characteristics of Ontario sewage plant influents, sludges and effluents.

The following describes our characterization of the metal content of Ontario sewage sludges (based on a 22 plant sample):

	Sludge (mg/L)		
	Average	Low	High
Zn	181	.60	650
Cu	19	.20	71
Ni	6.3	<.20	27
Pb	63	.60	330
Cd	.61	<.01	2.2
Cr	75	.02	300
Al	1826	16	11000
Mn	8.2	.24	40
Fe	4028	10	25000
Ca	5357	68	33000
Mg	660	12	3700
Ti	95	<.10	510
Li	.41	<.10	1.9
Co	.24	<.01	.75
Hg(ppb)	28	4.3	74
Sn	32	.20	180
V	1.6	<.01	8.9
As	.74	.008	2.4
Ba	18.2	.98	57
Sr	9.4	.49	32
Mo	1.2	.30	2.1
Ag	5	.50	9.6
Se	<.001	<.001	<.001

If present trends are not retarded or reversed, sewage sludge, in the foreseeable future, may ultimately be declared a hazardous substance and its use severely restricted. It is, therefore, necessary to point out the need for research directed towards the removal of metals from sludge and/or the stabilization of the metal content of sludge.

LAND DISPOSAL OF SEWAGE SLUDGE - FIELD AND GREENHOUSE STUDIES

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OBJECTIVE

The overall objective of this research was to determine maximum rates of sewage sludge application which can be used on agricultural soils without contaminating subsurface water with nitrate nitrogen and surface waters with elements or organisms pathogenic to humans and animals, and without reducing the yield or quality of the crops produced.

RUNOFF STUDIES

Materials and Methods

Runoff studies were started in the fall of 1972 on a tile drained sandy clay loam soil at both a 2% and 6% slope. Fluid digested sludge resulting from ferric chloride treated sewage was applied each November, January and May at rates supplying 200 and 800 kg N/ha. A check treatment received no sludge but did receive recommended rates of chemical fertilizers each spring. Grain corn was grown each year on all plots. Runoff was collected in a tank at the lower end of each plot and after each runoff event the amount was measured, samples taken for analysis and the tank emptied. Runoff collection was terminated in November, 1977.

Results and Discussion

Runoff was greater in the January to April (winter) period than in the May to November (summer) period. In winter, runoff was similar from the 6% and the 2% slopes, but in summer it was greater from the 6% slope. Soluble heavy metal losses were usually less than 5% of

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the total metal losses with little difference between times and rates of application. The greatest losses of nitrogen, phosphorus and metals tended to occur when sludge was applied immediately prior to a runoff event, as in the fall of 1974 (Table 1).

When sludge application was not immediately followed by rain, losses of nitrogen and phosphorus and metals from treatments receiving sludge were not markedly different from those from the control treatment receiving chemical fertilizer.

SLUDGE RATE AND SOURCE STUDIES IN THE FIELD

Materials and Methods

Field experiments were started in the spring of 1973 and are continuing. Fluid digested sludges resulting from calcium hydroxide, aluminum sulphate and ferric chloride treatment of sewage were applied at rates supplying 200, 400, 800 and 1600 kg N/ha each year and compared with ammonium nitrate at rates supplying 0, 100, 200 and 400 kg N/ha each year. Three experiments were cropped with grain corn, one on a Caledon loamy sand, one on an Oneida clay loam (abandoned in 1975) and one on a Conestoga loam. Sludge was applied in the spring after plowing and was disked in after it had dried. A fourth trial was under bromegrass on the Conestoga loam. Treatments in the bromegrass trial were the same as for the corn trials except that the annual sludge rates were divided into three equal applications, one in early spring and one after each of the first two cuts, and left on the soil surface.

Results and Discussion

The 1977 bromegrass yield responses to sludge applications are shown in Table 2. The 1977 season was the fifth year of sludge application to the bromegrass and corn trials. The 1977 data for the corn experiments were not available at time of writing so the 1976 corn yields on the Conestoga loam are presented in Table 3.

Bromegrass was quite responsive to nitrogen from ammonium nitrate or from sewage sludge. Nitrogen from sludge appears to be approximately as available as that from ammonium nitrate. This is a cumulative effect as the nitrogen in sewage sludge appeared to be less available than that in ammonium nitrate from yield measurements in the

first two years of the trial, 1973 and 1974. The bromegrass responded to rates of sludge supplying up to 800 kg N/ha although 400 kg/ha was the highest rate of nitrogen supplied as ammonium nitrate.

The corn on Conestoga loam was not as responsive to nitrogen fertilizers or sewage sludge as the bromegrass (Table 3). Response of corn to nitrogen was similar on the Caledon loamy sand to that presented except that the calcium sludge produced slightly but not significantly higher yields than the iron sludge.

Sewage sludge markedly increased the sodium bicarbonate-soluble soil phosphorus on all sites. Only the data for soil from the corn experiment on Conestoga loam are presented in Table 4. The sludge resulting from calcium treated sewage raised the sodium bicarbonate-soluble phosphorus much more than the other two sludges although the total amount of phosphorus added was least with the calcium sludge. This indicates that the phosphorus in the calcium sludge is probably much more available to plants than that in the iron and aluminum sludges. The total amount of phosphorus added in the sludges at the 1600 kg N/ha rates over four years totalled 3400, 5010 and 5920 kg P/ha for the calcium, aluminum and iron sludges, respectively. Phosphorus content of the corn and bromegrass was quite high but was little affected by treatment in any of these trials.

Soil pH was increased by the calcium sludge and tended to be lowered slightly with the ammonium nitrate and iron sludge as shown on the Conestoga loam soil (Table 5). Calcium content of the corn crop was not increased by calcium sludge applications but the calcium concentration of bromegrass was increased slightly.

Aluminum content of the crop was not increased by the aluminum sludge nor iron content by iron sludge.

Of all the metals studied cadmium is the one of greatest concern in sewage sludges from a human and animal health standpoint. Cadmium concentration in bromegrass has been rather variable from year to year but an increase due to aluminum and iron sludges has become more pronounced in recent years (Table 6). Total amounts of cadmium applied in sludge over the five years at the 1600 kg N/ha application rate were 2.0, 4.64, and 3.04 kg Cd/ha for the calcium, aluminum and iron sludges, respectively.

On the Conestoga loam, the cadmium content of corn stover in 1976 was more than doubled by the application of the iron sludge (Table 7). Total amounts of cadmium applied at the 1600 kg N/ha rate over the four years were 1.6, 3.76 and 2.80 kg/ha in the calcium, aluminum, and iron sludges, respectively. On the Caledon loamy sand the pattern in corn stover cadmium concentrations was similar to that with the Conestoga loam but concentrations were greater on all treatments. Cadmium concentration in corn grain was not affected by treatment.

Nickel concentration was increased slightly by sludge application in 1976 in the bromegrass and in the corn stover on the Caledon loamy sand. The source of calcium sludge was changed to one quite high in nickel for the 1976 applications. In 1977 the nickel concentration in bromegrass was increased from 0.8 to 6.0 µg/g with application of calcium sludge (Table 8). The highest rate of calcium sludge had supplied 421 kg Ni/ha up to and including 1977 applications.

Chromium, copper, nickel and lead in bromegrass were all increased by sludge application. Each of these metals was increased significantly in corn stover in one of the three corn trials.

Zinc concentration was increased by sludge application in all three cuts of bromegrass, in corn stover from all three sites and in corn grain from two of the three sites. Ammonium nitrate also increased the zinc concentration in the bromegrass (Table 9). Total amounts of zinc applied to the bromegrass over the five years at the 1600 kg N/ha application rate were 520, 712 and 448 kg Zn/ha for the calcium, aluminum and iron sludges, respectively.

Mercury content of the bromegrass and corn grain and stover was not affected by sludge application, the maximum amount applied over the three-year period being 2.08 kg/ha. Molybdenum and selenium concentrations in bromegrass may have been increased slightly when 0.41 kg Se/ha and 0.96 kg Mo/ha were applied in sludge. Molybdenum and selenium concentration in corn grain and stover did not appear to be affected by treatment.

GREENHOUSE RATE AND SOURCE STUDY

Materials and Methods

Eleven crops of annual ryegrass have been grown in this trial at time of writing, with sludge applied to the soil and worked in on some treatments before each crop was seeded. As data from the last three crops are still being analysed only the first eight crops are presented here. The number of treatments has been reduced over the years in this trial because of limited funds. At the present time, sludges from six different sewage plants, selected because of high metal content, have been applied to a Grimsby sandy loam soil at rates supplying 200, 800 and 1600 kg N/ha. One additional treatment received the first 1600 kg N/ha application of sludge and no further applications until after the fifth crop. At the end of the fifth crop all treatments were divided in two with half receiving sludge and half receiving no further sludge applications.

Results and Discussion

Dry matter yields of ryegrass resulting from sludge applications are presented in Table 10. Continued high rates of application of some sludges, the Fergus sludge for example, reduced the yield of ryegrass. With others such as the Guelph sludge the high rates increased yield slightly. We believe the low yields with Fergus sludge were due to copper toxicity. We do not know the reason for some of the other responses.

Cadmium concentration in the ryegrass was increased by most sludges but the effect was most marked with the Guelph sludge which supplied the greatest amount of cadmium, an average of 9.0 kg Cd/ha per application of the 1600 kg N/ha rate (Table 11). Cadmium concentrations in the ryegrass for the first eight crops are presented in Table 12. Cadmium concentration increased with rate of sludge application in any one crop. Cadmium concentration in ryegrass was as high, on the average, in the eighth crop, which had received only the first five sludge applications, as in treatments receiving eight applications. This effect was not consistent across sludges, some showing higher and some lower cadmium concentrations with only five applications.

There was little if any increase in cadmium concentration from the first crop to the fifth, however, in spite of the fact that by the time the fifth crop was grown, five times as much cadmium had been applied as for the first crop at each of the three rates of sludge application. After the fifth crop cadmium concentration began to increase with higher rates of the Guelph sludge.

Copper, nickel and zinc give similar concentration patterns to cadmium in the eighth crop of ryegrass (Tables 13, 14 and 15).

The Fergus sludge applied at high rates resulted in very low yields (Table 10). The Fergus sludge also produced the highest concentrations of copper in the ryegrass (Table 13) and it is believed that copper toxicity was the cause of this low yield. The yield depression with the Fergus sludge was apparent in the first crop but increased in severity up to the third crop, after which it remained relatively constant. There was a marked increase in zinc concentration after the fifth crop of ryegrass with the Sarnia sludge, which supplied 6,770 kg Zinc/ha up to the eighth crop. This trend was not apparent with sludges lower in zinc (Table 16). There were no consistent increases in copper or nickel concentration from the first to the eighth crop.

Molybdenum concentration in the ryegrass was increased by sludge application. The highest molybdenum concentration in the ryegrass was 1.85 µg/g in the third crop and eighth crop with sludges which had supplied totals of 5.0 and 24.0 kg Mo/ha, respectively. Ryegrass from the control treatment contained 0.25 and 0.33 µg Mo/g in the third and eighth crops. The ammonium nitrate fertilized ryegrass did not change appreciably in molybdenum concentration from one crop to the next.

Mercury concentration in ryegrass was not affected by sludge application, although up to 9.6 kg Hg/ha were applied in individual sludges in the eight sludge applications.

Selenium concentration in the ryegrass appears to have been increased by sludge application although the concentrations were low and rather inconsistent. Up to 9.4 kg Se/ha were added in individual sludges in the eight sludge applications (Table 17).

SOIL SALINITY

Soluble salts have not been a problem in the field experiments even at the highest rates of sludge application, 1600 kg N/ha each year. Precipitation in the Guelph area averages 84 cm/year and is rather consistent, with the result that soluble salts would be expected to leach out of the root zone. In the greenhouse experiment the bottom of the pots were closed and pots were watered by weight to 1/3 bar tension. Salts did build up in the pots to the extent that it was necessary to leach the excess salts after every second crop to keep salt levels in the normally accepted range for crop growth. One can therefore predict that soluble salts would pose a problem if high rates of sludge were applied in the field, in less humid regions. Of nine sludges studied in this project the highest potassium and sodium contents were 0.04% and 0.034% on a wet weight basis. At the 1600 kg N/ha rate of sludge application these resulted in 291 kg K/ha and 464 kg Na/ha per application. One sludge contained 3.7 µg boron/g on a wet weight basis. At the 1600 kg N/ha rate of sludge application this provided 5.63 kg B/ha in one application, sufficient to prevent the growth of some boron sensitive crops if it were all in soluble form. After six applications of this sludge the boron concentration in the ryegrass was 108 ppm, an extremely high level. When applied at more reasonable rates none of the sludges tested is expected to result in toxic concentrations of boron for most crops under Ontario conditions. In dry areas boron would be expected to pose a crop production problem if high boron sludges were used.

NITROGEN STUDIES

Field Sampling

Soils in the corn and grass experiments were sampled at five depths at several times during the year and NO_3^-, NH_4^+ and pH were determined at each depth. In May there was considerable nitrate present in profiles receiving sludge except in the Caledon loamy sand. Nitrate accumulated in the spring after sludge application and was quite high in September when the corn crop had completed its growth as shown for the loamy sand in Table 18. The nitrate level was appreciably lower in the loamy sand by November 27, presumably due to leaching. The decrease in

the fall was apparent to a lesser extent in the Conestoga loam soil under corn. Nitrate levels under grass were lower than under corn but at the highest rate sampled (800 kg N/ha) they did tend to build up in September and November. The quantity of NH_4^+ in the soil profiles was not greatly affected by the sludge applications, probably reflecting the rapid nitrification of NH_4^+.

In general soil solution sampling at 45 and 90 cm depth agreed with the soil sampling for nitrate. In most cases the NO_3^--N concentration exceeded 10 µg/ml.

Nitrification of Sludge Nitrogen

Six sludges were leached to remove soluble nitrogen and were then incubated with soil in the laboratory for 49 weeks during which the amount of nitrate produced was monitored. Approximately two-thirds of the organic nitrogen in these sludges was mineralized and measured as NO_3^--N in the 49 weeks. There were differences among sludges in the rate and amount of NO_3^--N produced. Hydrolysis of the sludges showed that the sludge which produced the least nitrate was lower than the other sludges in amino acid-N and non-hydrolysable nitrogen.

Ammonia Volatilization in the Field

Agrometeorology facilities and computerized monitors at the Elora Research Station were used to measure NH_3 flux from the surface of newly applied sewage sludge. The objective was to measure the losses of NH_3 from surface applications.

Daily losses of NH_3 from fluid sludge applied May 8 and October 8, 1975 are presented in Table 19. Warm sunny weather prevailed during the May experiment whereas cloudy cool weather with occasional showers prevailed during most of the October experiment. In both experiments it is obvious that an appreciable portion of the NH_4^+-N in fluid sewage sludge can be lost when it is applied to the soil surface. However, the lower proportion of N lost in the October period may be related to the cooler moister weather and/or the lesser amount of NH_4^+-N applied in the sludge than in the May application.

MICROBIAL STUDIES

The objective of this phase of the program has been to establish the numbers of some groups of indicator bacteria in runoff waters and sludges and to determine the presence or absence of such human pathogenic types as members of the genera Salmonella and Shigella in sludges, runoff waters and on plant material harvested from plots receiving the sludges.

Materials and Methods

Samples of sludges and of runoff waters were examined as soon as possible following application of sludge and collection of runoff. For the detection of Salmonella and Shigella, 250 g sludge or 250 ml runoff aliquots were added to duplicate flasks of the following enrichment media:

Tetrathionate Broth (Difco #0491)
Selenite Brilliant Green Sulfa Broth (Difco #0715)
GN Broth (Difco #0486)

A flow diagram of the procedure used is presented in Figure 1.

The most probable numbers of coliforms and faecal coliforms were estimated by a multiple tube dilution procedure using Lauryl Tryptose Broth and Brilliant Green Bile Broth at 37°C and EC Broth at 44.5°C. The most probable numbers of faecal streptococci were estimated by a multiple tube procedure with KF Streptococcus Broth.

Corn plant samples for microbial study were taken from the Field Source and Rate Experiments when plants were at the four to six-leaf stage. Some samples were also obtained from an Elgin county farm which had not received sewage sludge but had received animal manure and chemical fertilizers.

Grass samples were obtained from each of three cuttings per year of the bromegrass experiment.

Results and Discussion

Sludges

During the period May 1973 to March 1976 Salmonella species were detected in 20 of 54 sludge samples. Numbers of indicator organisms

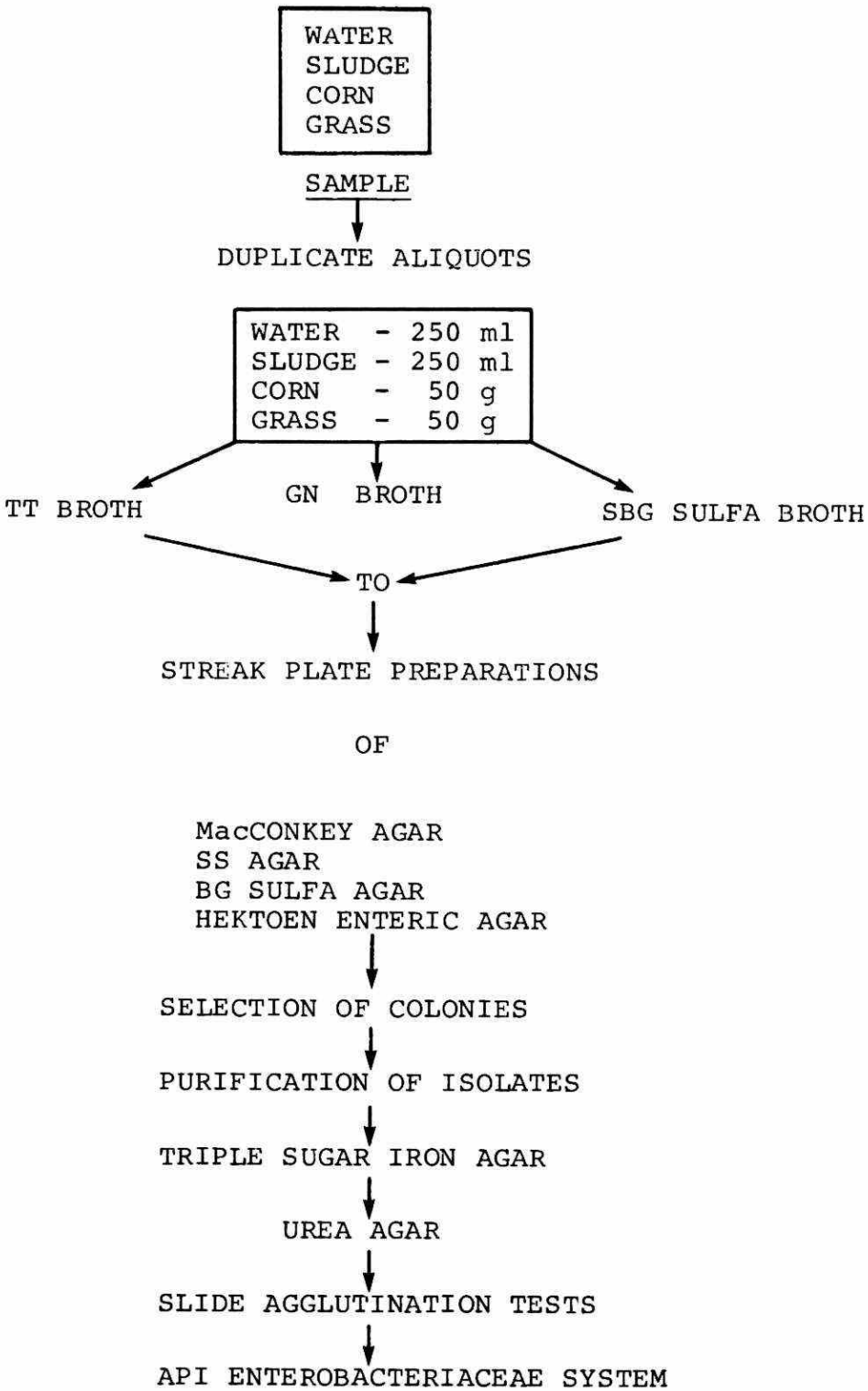

FIGURE 1. DETECTION OF SALMONELLA - SHIGELLA

in the North Toronto sludge samples are presented in Table 20. Similar values were obtained for Newmarket and Kitchener sludges.

Runoff

Microbial studies of runoff produced rather variable results with the sludge treatments not consistently higher in faecal coliforms or faecal streptococci than the treatments receiving chemical fertilizers. Of 484 samples of runoff studied, Salmonella were detected in one.

Corn and Grass

Salmonella were detected in one out of 96 samples of grass and in four out of 111 samples of corn. The corn samples showing Salmonella were all taken from plots receiving the highest rate of calcium sludge.

CONCLUSIONS

Runoff

Sewage sludge application did not result in marked increases in runoff of nutrients, heavy metals or bacteria on the 2% and 6% slopes used in this study except when heavy rain occurred immediately after sludge application.

Crop Growth and Nutrient Supply

Sewage sludges supply nitrogen and phosphorus for crop production but are low in potassium. Sludge produced at least as high yields as were produced with chemical fertilizers. Calcium, iron and aluminum added to sewage for phosphorus removal have not caused crop production problems although phosphorus in the calcium sludge appears to be more plant-available as measured by extraction with sodium bicarbonate than phosphorus in aluminum or iron sludges. Phosphorus in calcium sludge also increased sodium bicarbonate soluble ("plant available") soil phosphorus more than equivalent amounts of fertilizer phosphorus.

Metals

Applications supplying 200 to 400 kg N/ha per year from sludges low in metals are not likely to elevate levels of metals in crops for a number of years.

In general increasing rates of sludges high in cadmium, copper, nickel, lead and zinc increased the metal content of grass and corn stover. Re-application of the sludges before re-cropping did not lead to increased crop metal concentration from one crop to the next, except with high rates of sludges very high in metals. In the greenhouse metal concentrations appeared to decrease slowly in some cases and to increase in others in crops grown after sludge application had ceased.

Large amounts of metals are added to soils in some sludges and their removal by crop uptake or leaching is very limited. It is therefore important that we learn to predict their availability to crops for many years after application. The research reported has raised more questions than it has provided answers in this regard.

Toxic salts

Soil salinity was not a problem in the field under Ontario conditions. It could pose a serious problem in less humid areas. Boron levels in some sludges tested would also be expected to pose a problem in arid regions.

Nitrogen Studies

Organic nitrogen in sludges is mineralized gradually and the mineralization rate varies from one sludge to another. As with other sources of nitrogen, applications in excess of crop requirements will lead to high levels of nitrate in the soil solution.

The average NH_4^+-N content of sludges studied was 1.3% on a dry weight basis or 27% of the total nitrogen. In two experiments 61% and 56% of the NH_4^+-N was lost by volatilization from sewage sludge applied to the soil surface. This loss occurred in five and eight days, respectively.

Microbial Studies

The fluid digested sewage sludges used in these studies contained appreciable numbers of coliforms, faecal coliforms and faecal streptococci. On the crops grown, however, Salmonella were isolated from only five samples out of a total of 207 plant samples tested. If vegetables are not grown and animals not grazed on areas receiving sludge, and if reasonable care is exercised in spreading, sludge does not pose a serious health hazard through the crops grown.

TABLE 1. NUTRIENTS AND METALS IN RUNOFF, NOVEMBER 20, 1974 TO JANUARY 14, 1975 IN THE EXTREME SITUATION WHEN 27.9 mm OF RAIN FELL IMMEDIATELY AFTER SLUDGE APPLICATION

Nutrient or Metal	Sludge Application			
	No Sludge	200 kg N/ha Fall Applied		800 kg N/ha Fall Applied
		6% slope	2% slope	2% slope
	kg/ha			
nitrogen	0.03	0.79	0.15	13.2
phosphorus	0.01	0.22	0.09	3.0
cadmium	0.0001	0.0032	0.0002	0.011
copper	0.0001	0.088	0.0055	0.38
nickel	0.00042	0.0088	0.0014	0.036
lead	0.0018	0.126	0.019	0.604
zinc	0.0029	0.147	0.011	0.662
mercury	0.0001	0.001	0.0006	0.0078

TABLE 2. TOTAL DRY MATTER YIELD OF BROMEGRASS, CONESTOGA LOAM, 1977 (3 cuts)

Nitrogen Rate kg/ha	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	Sludge Average
		kg/ha			
0	3050 g				
100	6440 f				
200	8130 cd	6880 ef	7020 ef	7630 de	7180
400	8820 bc	9250 ab	9370 ab	9050 ab	9220
800		9820 a	9360 ab	9510 ab	9560
1600		8960 abc	9510 ab	9690 ab	9390
Average		8730	8820	8970	8840

C.V. = 6.1%

Individual treatments not followed by a common letter are significantly different at 0.05 probability by Duncan's Multiple Range Test.

Rates of sludge and of NH_4NO_3 are significantly different at 0.01 probability by "F" test.

TABLE 3. EFFECT OF RATE AND SOURCE OF NITROGEN ON CORN GRAIN YIELD ON CONESTOGA LOAM, 1976.

Nitrogen Rate kg/ha	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	kg/ha				
0	6420 e*				
100	7460 a-d				
200	6900 c-e	7050 b-e	7540 a-d	7350 a-d	7320
400	6890 c-e	6770 de	7080 b-e	7570 a-d	7140
800		7280 a-e	7750 abc	7980 a	7670
1600		7150 a-e	7250 a-e	7860 ab	7420
Average		7060	7410	7690	

C.V. = 6.1%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of ammonium nitrate are significantly different at 0.05 probability level by "F" test.

TABLE 4. SODIUM BICARBONATE-EXTRACTABLE PHOSPHORUS IN SURFACE SOIL (0-6 in). CONESTOGA LOAM CORN EXPERIMENT. FALL, 1976

Nitrogen Rate kg/ha	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	P ug/g				
0	23 f*				
100	30 f				
200	30 f	87 c-f	57 ef	53 ef	66
400	40 ef	87 c-f	80 def	90 c-f	86
800		210 b	90 c-f	150 bcd	150
1600		290 a	117 cde	160 bc	189
Average		168	86	113	123

C.V. = 41%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources and rates of sludge, and rates of ammonium nitrate are significantly different at 0.01 probability by "F" test. Source x rate interaction is significant at 0.05 probability level.

TABLE 5. SURFACE SOIL (0-15 cm) pH, CORN EXPERIMENT, CONESTOGA LOAM. FALL, 1976

Nitrogen Rate kg/ha	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		Soil pH			
0	7.30 de*				
100	7.63 bc				
200	7.03 e-g	7.97 a	7.13 d-g	7.40 cd	7.50
400	7.13 d-g	7.73 ab	7.27 def	7.10 d-g	7.37
800		7.93 a	7.40 cd	6.97 fg	7.43
1600		7.80 ab	7.23 def	6.87 g	7.30
Average		7.86	7.26	7.09	7.40

C.V. = 2.3%

*Individual treatments followed by a common letter are not significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Sources of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test. Source x rate interaction is significant at 0.05 probability level.

TABLE 6. CADMIUM CONCENTRATION IN FIRST CUT (JUNE 8) BROMEGRASS. ELORA, 1977

Nitrogen Rate kg/ha	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	cd ug/g				
0	0.07 de*				
100	0.07 de				
200	0.07 de	0.05 e	0.10 cde	0.07 de	0.07
400	0.10 cde	0.05 e	0.08 cde	0.12 cd	0.08
800		0.07 de	0.13 bc	0.17 ab	0.12
1600		0.08 cde	0.18 a	0.20 a	0.16
Average		0.06	0.13	0.14	0.11

C.V. = 28%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range test.

Sources and rates of sludge, and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test. Source x rate interaction is significant at 0.05 probability level.

TABLE 7. CADMIUM CONCENTRATION IN CORN STOVER AT HARVEST. CONESTOGA LOAM, 1976

Nitrogen Rate kg/ha	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
	ug Cd/g				
0	0.22 f*				
100	0.30 def				
200	0.35 def	0.30 def	0.33 def	0.27 ef	0.30
400	0.33 def	0.37 def	0.57 abc	0.47 bcd	0.47
800		0.37 def	0.60 ab	0.67 a	0.54
1600		0.43 cde	0.67 a	0.70 a	0.60
Average		0.37	0.54	0.53	0.48

C.V. = 20%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan'n Multiple Range Test.

Sources and rates of sludge and rates of ammonium nitrate are significantly different at 0.01 probability level by "F" test. Source x rate of sludge interaction is significant at 0.05 probability level.

TABLE 8. NICKEL CONCENTRATION IN FIRST CUT (JUNE 8) BROMEGRASS. ELORA, 1977

Nitrogen Rate kg/ha	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		Ni ug/g			
0	0.8 e*				
100	0.8 e				
200	0.8 e	2.6 c	0.9 e	0.7 e	1.4
400	0.7 e	3.5 c	0.8 e	0.8 e	1.7
800		4.7 b	1.1 de	0.6 e	2.1
1600		6.0 a	1.7 d	1.1 de	2.9
Average		4.2	1.1	0.8	2.0

C.V. = 14%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate and sources of sludge are significantly different at 0.01 probability level by "F" test. The source x rate interaction is significant at 0.05 probability level.

TABLE 9. ZINC CONCENTRATION IN FIRST CUT (JUNE 8) BROMEGRASS. ELORA, 1977

Nitrogen Rate kg/ha	Nitrogen Source				Sludge Average
	Ammonium Nitrate	Calcium Sludge	Aluminum Sludge	Iron Sludge	
		Zn ug/g			
0	14 g*				
100	14 g				
200	18 f	17 fg	19 f	18 f	18
400	22 de	19 f	23 de	23 de	22
800		22 e	28 bc	28 bc	26
1600		25 cd	30 b	34 a	30
Average		21	25	26	24

C.V. = 8.1%

*Individual treatments not followed by a common letter are significantly different at 0.05 probability level by Duncan's Multiple Range Test.

Rates of sludge and ammonium nitrate and sources of sludge are significantly different at 0.01 probability level by "F" test. The source x rate interaction is significant at 0.05 probability level.

TABLE 10. DRY MATTER YIELD OF 8TH CROP OF RYEGRASS WHICH RECEIVED SEWAGE SLUDGE BEFORE EACH CROP

Sludge	N rate			
	200	800	1600	Mean
	D.M. g/pot			
None				2.45
Aurora	2.30	2.45	2.10	2.28
Midland	2.25	2.60	2.35	2.40
Sarnia	2.25	2.50	2.35	2.37
Guelph	2.45	2.85	2.70	2.67
Fergus	2.85	1.10	0.30	1.42
N. Toronto	2.45	3.10	2.70	2.75
Mean	2.43	2.43	2.08	2.31

TABLE 11. CADMIUM CONCENTRATION IN 8TH CROP OF RYEGRASS AFTER ADDITON OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS

	Sludge Not Added Since 5th Crop			Sludge Added Before Each Crop			Mean
			N rate lb/ac (kg/ha)				
Sludge	178 (200)	712 (800)	1424 (1600)	178 (200)	712 (800)	1424 (1600)	
			Cd ug/g				
None							1.05
Aurora	0.65	0.55	0.55	0.35	0.55	0.60	0.73
Midland	0.38	0.55	0.75	0.30	0.45	0.40	0.48
Sarnia	1.30	1.54	2.20	2.10	1.75	2.50	2.05
Guelph	4.05	5.20	8.00	2.40	4.25	8.05	4.97
Fergus	0.80	1.40	1.90	0.95	1.10	0.60	1.13
N. Toronto	1.10	0.83	0.95	0.85	1.10	0.90	1.03
Mean	1.38	1.68	2.39	1.16	1.53	2.18	1.73

Sludge source - .01*
Sludge rate - .01
Sludge addition - .05

Source x rate - .01
Source x addition - N.S.
Addition x rate - N.S.
Source x rate x addition - N.S.

*Significance of "F" test at 0.05 and 0.01 probability

TABLE 12. CADMIUM CONCENTRATION IN CROPS 1 TO 8 OF RYEGRASS RECEIVING SEWAGE SLUDGES FROM GUELPH AND NORTH TORONTO BEFORE EACH CROP*

	Control (NH_4NO_3)	Guelph			North Toronto		
				kg N/ha			
Crop	200	200	800	1600	200	800	1600
			Cd - ug/g				
First	0.55	1.03	2.15	2.60	0.70	0.70	0.85
Second	0.35	1.10	2.65	5.61	0.45	0.35	0.40
Third**	0.40	0.65	1.90	2.45	1.45	0.55	0.70
Fourth	0.31	0.86	2.18	3.14	0.38	0.64	0.44
Fifth**	0.60	0.95	2.25	3.70	0.50	0.60	0.65
Sixth	1.65	2.05	4.10	5.20	1.00	0.60	0.50
Seventh**	1.45	2.08	4.05	6.18	0.89	0.79	0.75
Eighth	1.05	2.40	4.25	8.05	0.85	1.10	0.90

*The sludge from Guelph supplied the greatest amount of cadmium in the experiment, while the cadmium content of the North Toronto sludge is near the average of the sludges used.

**Pots were leached after sludge application but before seeding.

TABLE 13. COPPER CONCENTRATION IN 8TH CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS

	Sludge Not Added Since 5th Crop			Sludge Added Before Each Crop			Mean
	N rate lb/ac (kg/ha)						
Sludge	178 (200)	712 (800)	1424 (1600)	178 (200)	712 (800)	1424 (1600)	
	Cu ug/g						
None							10
Aurora	10	10	14	16	22	23	16
Midland	15	18	20	19	25	29	20
Sarnia	15	14	23	18	27	34	22
Guelph	17	16	21	21	29	32	23
Fergus	18	18	34	26	39	43	30
N. Toronto	17	13	12	21	27	26	20
Mean	15	15	20	20	28	31	22

Significance of "F" test at 0.05 and 0.01 probability -

Sludge source - .01
Sludge rate - .01
Sludge addition - .01
Source x rate - .01
Source x addition - N.S.
Addition x rate - N.S.
Source x rate x addition - N.S.

TABLE 14. NICKEL CONCENTRATION IN 8TH CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS

	Sludge Not Added Since 5th Crop			Sludge Added Before Each Crop			Mean
			N rate lb/ac (kg/ha)				
Sludge	178 (200)	712 (800)	1424 (1600)	178 (200)	712 (800)	1424 (1600)	
			Ni ug/g				
None							0.9
Aurora	1.1	1.3	1.4	1.1	1.2	1.2	1.2
Midland	7.7	19.5	30.0	12.9	28.0	42.0	27.4
Sarnia	1.1	1.0	1.4	1.2	1.4	2.2	1.4
Guelph	1.4	1.5	1.7	1.3	1.8	2.5	1.8
Fergus	1.4	3.5	8.2	1.9	10.5	4.0	5.2
N. Toronto	1.4	1.1	1.7	1.5	1.5	1.6	1.5
Mean	2.4	4.7	7.4	3.3	7.4	8.9	6.4

Significance of "F" test at 0.05 and 0.01 probability -

Sludge source - .01
Sludge rate - .01
Sludge addition - .01
Source x rate - .01
Source x addition - N.S.
Addition x rate - N.S.
Source x rate x addition - N.S.

TABLE 15. ZINC CONCENTRATION IN 8TH CROP OF RYEGRASS AFTER ADDITION OF SEWAGE SLUDGE BEFORE EACH OF THE FIRST FIVE CROPS

	Sludge Not Added Since 5th Crop			Sludge Added Before Each Crop			Mean
	N rate lb/ac (kg/ha)						
Sludge	178 (200)	712 (800)	1424 (1600)	178 (200)	712 (800)	1424 (1600)	
	Zn ug/g						
None							33
Aurora	36	30	50	27	48	63	43
Midland	31	51	68	37	64	94	56
Sarnia	118	187	318	178	309	530	279
Guelph	81	112	149	60	110	157	112
Fergus	85	238	408	143	388	320	284
N. Toronto	57	49	78	60	121	129	85
Mean	68	111	178	84	173	215	143

Significance of "F" test at 0.05 and 0.01 probability -

Sludge source - .01
Sludge rate - .01
Sludge addition - .01
Source x rate - .01
Source x addition - N.S.
Addition x rate - N.S.
Source x rate x addition - N.S.

TABLE 16. ZINC CONCENTRATION IN CROPS 1 TO 8 OF RYEGRASS RECEIVING SEWAGE SLUDGES FROM SARNIA AND NORTH TORONTO BEFORE EACH CROP*

	Control (NH_4NO_3)	Sarnia			North Toronto		
		kg N/ha					
Crop	200	200	800	1600	200	800	1600
		Zn ug/g					
First	43	59	167	241	53	64	72
Second	38	105	218	211	37	66	81
Third**	31	92	146	245	41	70	102
Fourth	32	64	156	103	29	68	112
Fifth**	33	44	122	165	30	58	92
Sixth	51	104	292	490	61	117	130
Seventh**	36	99	209	426	47	75	86
Eighth	33	177	309	530	60	121	130

*The sludge from Sarnia supplied the greatest amount of zinc in the experiment, while the North Toronto sludge may be considered to be average among the sludges used in its zinc content.

**Indicates pots were leached after sludge application but before seeding.

TABLE 17. SELENIUM CONCENTRATIONS IN RYEGRASS FROM SELECTED TREATMENTS

Sludge Treatments	Sludge not Added After 5th Crop	Sludge Added Before Each Crop
	Se ug/g	
6th Crop		
Aurora 1600 kg N/ha	0.04	0.07+
Midland 1600 kg N/ha	-	0.03
Midland 1600 kg N/ha*	-	0.03
Guelph 800 kg N/ha	-	0.04
Guelph 1600 kg N/ha	0.14	0.07
Control	---------- 0.02+ ----------	
7th Crop		
Aurora 1600 kg N/ha	0.06+	0.04
Midland 1600 kg N/ha	0.04+	0.04+
Midland 1600 kg N/ha*	-	0.03
Guelph 1600 kg N/ha	0.06	0.12
Control	---------- 0.02+ ----------	
8th Crop		
Aurora 1600 kg N/ha	0.06+	0.06+
Aurora 1600 kg N/ha*	0.05+	0.06
Midland 1600 kg N/ha	0.06+	-
Midland 1600 kg N/ha*	0.05+	0.04
Guelph 1600 kg N/ha	0.12+	0.04
Guelph 1600 kg N/ha*	-	0.11
Control	---------- 0.07+ ----------	

*Sludge added before first crops but not before crops 2, 3, 4 and 5.
+Indicates result of one of two replicates, or of samples composited from two replicates if plant material was insufficient.
Some treatments were analysed in one crop but not in another because of lack of material for analysis.

TABLE 18. NO_3-N CONCENTRATION IN A CALEDON LOAMY SAND PROFILE (CAMBRIDGE, CORN EXPERIMENT) IN PLOTS HAVING RECEIVED DIFFERENT QUANTITIES OF IRON SLUDGE. SAMPLED APRIL 22, JUNE 27, SEPTEMBER 15 AND NOVEMBER 27, 1975.

Date	Depth cm	Sludge Rate - kg N/ha 0	400	800
			NO_3-N ug/g	
22/4/75	0-15	2.4	3.3	3.0
	15-30	3.8	3.5	3.1
	30-45	4.2	5.4	3.4
	45-60	5.9	6.5	5.5
	60-90	4.3	4.4	5.0
27/6/75	0-15	16.3	38.4	82.8
	15-30	13.1	34.1	49.4
	30-45	6.8	17.7	36.5
	45-60	3.1	7.8	7.6
	60-90	4.2	10.4	7.1
15/9/75	0-15	4.6	6.7	10.2
	15-30	6.0	17.1	27.8
	30-45	4.8	18.5	25.9
	45-60	4.8	12.3	26.0
	60-90	3.3	5.8	15.9
27/11/75	0-15	3.1	3.7	7.6
	15-30	4.1	7.4	12.0
	30-45	3.7	7.9	10.5
	45-60	2.6	8.4	10.9
	60-90	1.5	6.2	10.6

TABLE 19. DAILY LOSSES OF AMMONIA VOLATILIZED DURING MAY AND OCTOBER, 1975

May Experiment		October Experiment	
Date	NH_3-N volatilized	Date	NH_3-N volatilized
	(kg/ha)		(kg/ha)
May 8*	22.2	Oct. 8**	16.4
May 9	36.5	Oct. 9	14.5
May 10	14.5	Oct. 10	4.2
May 11	8.9	Oct. 11	4.5
May 12	5.4	Oct. 12	3.9
May 13	3.4	Oct. 13	2.0
Total	90.9	Oct. 14	3.2
		Oct. 15	1.6
		Total	50.3
NH_4^+-N applied	150		89
NH_4^+-N lost as NH_3	61%		56%

*measurements begun at 1300 h

**measurements begun at 1200 h

TABLE 20. NUMBER OF SOME INDICATOR ORGANISMS IN NORTH TORONTO IRON SLUDGE

Microorganisms	Sampling Date						
	April 30/74	May 2/74	May 24/74	June 20/74	July 25/74	Nov.19/74	Jan.15/74
	most probable numbers/100 g						
Total Coliforms	200,000	12,500	45,000	1,200,000	1,550,000	1,260,000	260,000
Faecal Coliforms	37,000	200	0	500,000	550,000	107,000	126,000
Faecal Streptococci	16,000,000	1,900,000	1,600,000	11,000,000	8,320,000	73,000	24,000

LAND APPLICATION OF CHEMICAL SEWAGE SLUDGE - LYSIMETER STUDIES

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INTRODUCTION

A recent survey by Antonic et al (1978) indicates that application of sewage sludge to farmland during 1975 accounted for 34% (53,000 tons) of all sludge disposed in Ontario. Application to farmland is desirable because it takes advantage of the fertilizing and soil conditioning properties of sludges; however, it also involves risk. For example, many Water Pollution Control Plants in Ontario practice chemical addition to wastewater for phosphorus removal. The chemicals commonly used for this purpose are aluminum sulphate (alum), ferric chloride or waste pickle liquor (iron) and calcium oxide or hydroxide (lime) and there is little information concerning the environmental impact of these sludges in either liquid or dry forms when applied to agricultural soils. Other risks include the introduction of pathogenic organisms and phytotoxic materials into the food chain. The potential for harmful effects on soils, groundwater and plants of deleterious substances such as heavy metals in sludges are of particular concern to public health authorities and regulatory agencies.

The long-term risks of applying sewage sludges to farmland must be assessed. The estimates of risk should then be incorporated into guidelines or standards which determine with reasonable safety margins a permissible code of practice. The standards should state clearly the maximum permissible concentrations of toxic or undesirable constituents in sludge, soil, plants, runoff, and leachate to groundwater. These "ideal" standards must be based on an acceptable baseline of scientific information, much of which is lacking. This report concerns an attempt to obtain scientific information by conducting long-term lysimeter studies in which soil, sludge, plant and leachate quality have been monitored continuously.

OBJECTIVES

One lysimeter experiment employing fluid sludges and a second employing air-dried sludges were initiated at the Wastewater Technology Centre, Burlington, Ontario in 1973 and 1974, respectively. The major objectives of these studies were to determine maximum sludge loading rates which can be applied to agricultural soils without causing harmful effects to crop yield, crop quality and groundwater quality. Secondary objectives were to compare results with field and greenhouse studies at the University of Guelph.

EXPERIMENTAL

Fluid Sludge Experiment

The fluid sludge experiment, begun in 1973, was designed as a randomized block of 66 lysimeters with two soil types and eleven fertility treatments replicated three times. The fertility treatments included three rates of three sludges and two controls. The soils were Caledon loamy sand and Conestoga silt loam and were the same ones on which the University of Guelph field trials are located. Alum, iron and lime sludges supplied approximately the nitrogen requirement for orchard grass, and two and three times the requirement. Neither control treatment received sludge but one received NPK commercial fertilizer. The sludges were applied at rates of 100, 200 and 300 kg total Kjeldahl nitrogen (TKN)/ha and NPK fertilizer was applied to the control at 100, 33.3 and 33.3 kg/ha N, P and K, respectively. Applications were made at the beginning of all but one growing season and following all but one harvest of orchard grass. The sludges and fertilizer were applied, 3, 5, 5, 4 and 5 times, respectively, during 1973, 1974, 1975, 1976 and 1977. Sewage sludge contains little potassium and deficiency symptoms were observed late in the 1974 growing season. Thereafter, muriate of potash at 200 kg K/ha was applied to all sludge and the NPK control treatments at the beginning of each growing season.

Air-Dried Sludge Experiment

The air-dried sludge experiment, begun in 1974, was designed as a randomized block of 44 lysimeters with two soil types and eleven

fertility treatments replicated two times. The fertility treatments included three rates of three sludges and two controls. The soils were Plainfield sand and New Liskeard clay. Applications of alum, iron and lime sludges during 1974 were related to the Chumbley (1971) "zinc equivalent" (ZE) formula based on the relative toxicities to plants of zinc, copper and nickel. The maximum recommended ZE application is 19 kg/ha•yr. Air-dried sludges were applied on two occasions during 1974 to the surface 15 cm of soil at cumulative rates of 114, 228 and 342 kg ZE/ha giving a maximum loading 18 times the recommended maximum annual rate. No sludge was applied during 1975 or the growing season of 1976 but then additional alum and iron sludges were added following the final 1976 harvest. Neither control treatment received sludge but one received NPK commercial fertilizer at 60, 60 and 60 kg/ha N, P and K, respectively when crops were seeded. Fall wheat received an additional 60 kg N/ha when spring growth began. Muriate of potash at 60 kg K/ha was applied to all sludge treatments when fall wheat was planted in 1976. To date, fall wheat (1975) and spring wheat (1974 and 1976) have been grown to maturity and buckwheat (1975) has been grown as a cover crop during the experiment. Following harvest, the fall and spring wheats were threshed and the grain and straw were analyzed separately.

Sludge Sources

Attempts were made to use the same alum, iron and lime sludges in the lysimeter experiments as were used in the Guelph field experiments. However, changes in the chemical used for phosphorus removal at the water pollution control plants coupled with timetable and transportation problems made this objective unrealistic. The ferric chloride sludge from North Toronto and the lime treated sludges from Newmarket and Midland were the same ones used by Guelph and the constituent loadings were similar. Alum sludges were obtained from Point Edward, Tillsonburg and Kitchener and differed markedly among themselves. Consequently, sludge constituent loadings from alum sludges, particularly for some heavy metals, were markedly different for the lysimeter and field experiments.

Leachates

In addition to normal precipitation, the experiments were irrigated as required to maintain soil moisture content greater than or equal to one-third field capacity. Equal volumes of water were supplied to all treatments in each experiment. Leachate from the lysimeters was collected and analyzed.

Further experimental details are summarized by Cohen and Bryant (1978).

RESULTS

Sludge Properties

The average chemical compositions of fluid and air-dried sludges applied to the lysimeter experiments indicated that they were low-grade fertilizer materials (Table 1). Their total Kjeldahl nitrogen (TKN) and phosphorus contents were $\leq$ 5% dry wt. basis, potassium < 0.2% and magnesium < 1.5%. In general the sludges contained appreciable quantities of Zn, Cu, Pb and Cr and smaller amounts of Cd, Ni, Mo, As and Hg. The 749 µg Ni/g average value for Ni in lime fluid sludge resulted from applications during 1976 of Midland sludge which contained 2530 µg Ni/g.

Sludge Loadings

Application rates to all sludge treatments in the lysimeter experiments were much larger than the 2 tonnes dry sludge solids/ha average annual rate for Ontario farmland (Antonic et al, 1978). The high rates of fluid and air-dried sludges (Table 2) were equivalent to average annual rates ranging from 29 to 76 and 43 to 142 tonnes/ha, respectively. The medium and low rates were two-thirds and one-third of the high rates.

The high rates of sludges supplied large amounts of nitrogen and phosphorus but small amounts of potassium for crop growth. In addition, they supplied Cd, Zn, Cu, Pb, Mo and Hg in approximately the amounts recommended as maxima for Ontario agricultural land (Table 2). The Ni, Cr and As additions were generally smaller than the recommended maxima. The 311 kg Ni/ha from lime, fluid sludge reflects the large amount added in Midland sludge during 1976. The potassium supply in sludge treated soils was supplemented with muriate of potash as outlined in the Experimental Section.

TABLE 1. WEIGHTED MEAN CHEMICAL COMPOSITIONS OF SLUDGES APPLIED (dry wt. basis)

Constituent	Fluid, 1973-1976			Air-Dried, 1974-1976		
	Alum	Iron	Lime	Alum	Iron	Lime
TKN-N %	4.4	4.7	2.1	3.1	2.9	1.7
NH_4-N %	0.8	1.0	0.3	-	-	-
Total P %	3.8	2.6	1.6	5.1	4.0	1.7
Fe %	1.2	7.5	1.1	1.4	7.2	0.6
Al %	4.6	1.5	0.4	5.8	1.0	0.3
Ca %	8.7	5.0	42.7	5.5	6.6	26.3
Mg %	0.9	0.7	1.2	0.49	0.58	0.35
K %	0.16	0.22	0.10	0.08	0.08	0.04
Cd µg/g	26	27	5.7	14	27	3.8
Zn "	1898	2939	1250	1174	2059	375
Cu "	1026	1404	328	687	1089	168
Ni "	35	26	749	18	18	8
Cr "	515	583	276	179	512	34
Pb "	656	1968	193	393	1569	111
Mo "	7.5	7.8	2.3	5.2	11	nd*
As "	59	37	28	-	-	-
Hg "	4.2	4.0	0.9	-	-	-

* Not detected

TABLE 2. SLUDGE CONSTITUENT LOADINGS AT THE HIGH RATES* (kg/ha, dry wt. basis)

Constituent	Fluid Sludge, 1973-1976			Air-Dried Sludge, 1974-1976			Maximum Recommended Metal Additions to Agricultural Land **
	Alum	Iron	Lime	Alum	Iron	Lime	
TKN-N	5100	5100	5100	5167	3604	6984	
NH_4-N	984	1232	848	-	-	-	
Total-P	4589	2730	4352	9528	5483	7912	
Fe	1479	8632	3094	2983	9336	2797	
Al	6380	1726	1037	10583	1299	1096	
Ca	10542	6056	159940	10574	8944	113368	
Mg	1139	930	3416	920	707	1567	
K	189	273	284	179	100	166	
Cd	3.2	3.1	1.8	2.7	3.6	1.5	1.6
Zn	228	355	391	242	267	164	363
Cu	124	162	101	146	143	73	168
Ni	4.6	3.2	311	4.8	2.3	3.5	36
Cr	62	67	111	34	65	14	220
Pb	79	228	57	82	201	46	94
Mo	0.9	1.2	1.1	1.2	1.6	nd***	2.7
As	6.5	5.9	12.9	-	-	-	14.6
Hg	0.47	0.61	0.36	-	-	-	0.9
Total Solids (tonnes/ha)	126.1	115.1	305.5	203.5	129.9	425.8	

* Lowest loading = 1/3 and medium loading = 2/3 of the values listed

** Source: OMAF/OMOE (1976) Provisional Guidelines for sludge utilization on agricultural land

*** Not detected

Crop Yields

Silt loam soil produced higher 1973-1977 cumulative yields of orchard grass than the corresponding treatments of loamy sand soil (Table 3). However, both soils exhibited increased yields with increasing fluid sludge application and generally higher yields with iron than with the alum or lime sludges. The NPK treatment yields were larger than the medium sludge rate yields but smaller than the high sludge rate yields, indicating that approximately twice as much TKN was required in sludge as in commercial fertilizer to produce equivalent yields.

Annual yields of orchard grass for the NPK and medium application rates of sludge treatments are illustrated in Figure 1. The silt loam soil always yielded more than the loamy sand; however, there were small inconsistent differences between the treatments. Yields increased to high levels during 1973-1975, decreased slightly in 1976 and decreased markedly in 1977. Yield reduction was probably due to reduced plant population observed for all treatments. Annual yield data for the low and high sludge rates exhibited similar trends.

Clay soil produced higher 1974-1977 cumulative yields of wheat/buckwheat than the corresponding treatments of sand soil (Table 3). Yields from the medium and high rates of alum sludge on sand approximated that from NPK, but the yields from all rates of iron and lime sludges on sand were less than from NPK.

Total plant material yields of wheat/buckwheat exhibited wide variations between years but were consistently larger from the clay than the sand soil (Figure 2). The low yields of buckwheat in 1977 were due partly to damage resulting from soil infestation with June bug larvae. In general, the NPK and sludge treatment yields were similar for all crops grown on the clay soil and for the 1974 spring wheat, 1975 fall wheat and 1977 buckwheat grown on sand. There were appreciable differences between treatments for the 1976 and 1977 spring wheat crops grown on sand. The authors have no satisfactory explanation for these differences. Yield data for the low and high sludge rates exhibited similar trends.

TABLE 3. CUMULATIVE YIELDS OF PLANT DRY MATTER (tonnes/ha) FROM THE FLUID SLUDGE - ORCHARD GRASS (1973-1977) AND AIR-DRIED SLUDGE-WHEAT/ BUCKWHEAT (1974-1977) EXPERIMENTS

Treatment (kg TKN/ha)	Orchard Grass		Treatment (kg TKN/ha)	Wheat/Buckwheat	
	Loamy Sand	Silt Loam		Sand	Clay
NPK (2336)	65	76	NPK (600)	37	47
Alum (2200)	37	53	Alum (2328)	32	49
(4400)	57	72	(4656)	36	49
(6600)	70	89	(6984)	38	50
Iron (2200)	40	55	Iron (2328)	28	47
(4400)	58	74	(4656)	30	49
(6600)	78	98	(6984)	32	50
Lime (2200)	35	50	Lime (2328)	25	48
(4400)	55	69	(4656)	32	49
(6600)	68	87	(6984)	32	48

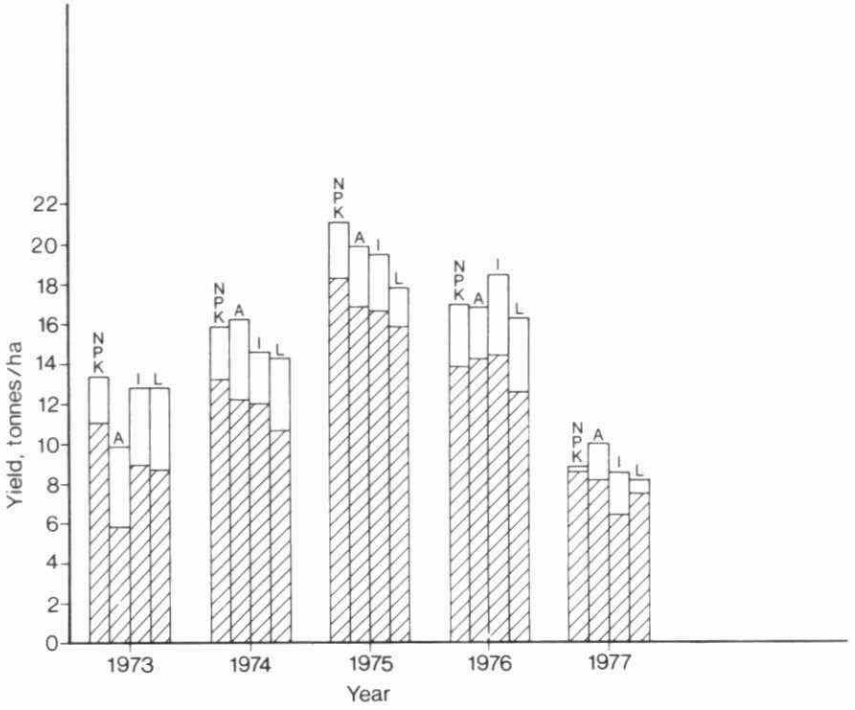


FIGURE 1. Annual yields of orchard grass treated with NPK fertilizer and the medium rates of alum (A), iron (I), and lime (L) sludges. Silt loam soil – total bar / Loamy sand soil – hatched bar.

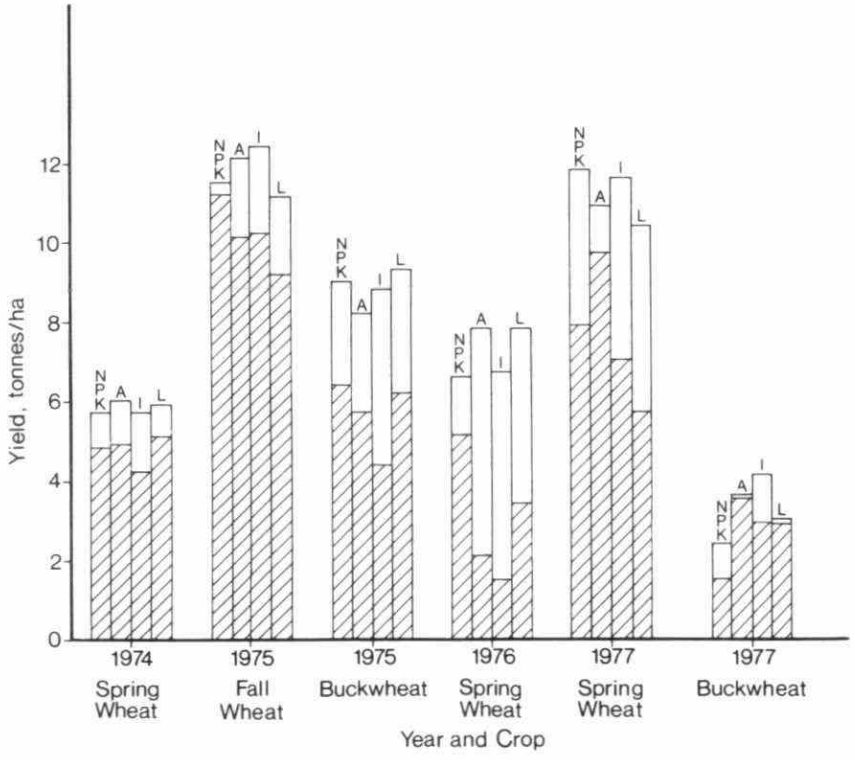


FIGURE 2. Total plant material yields of wheat / buckwheat treated with NPK fertilizer and the medium rates of air-dried alum (A), iron (I), and lime (L) sludges. Clay soil – total bar / Sand soil – hatched bar.

Crop Quality

The Cd content of orchard grass grown on loamy sand soil decreased markedly from 1973 to 1974 and then remained approximately constant through 1976 (Table 4). The sludge treatments exhibited higher Cd levels than the NPK control but there was no difference between the mean for all sludge application rates and the high sludge rates. The Zn contents increased markedly from 1973 to 1974 but then decreased and remained approximately constant during 1975 and 1976. Zinc contents increased with increasing sludge rate. Copper contents increased with increasing sludge rate and exhibited small increases with time. Similar data were obtained for other heavy metals in the orchard grass grown on loamy sand soil, for orchard grass grown on the silt loam soil and for wheat and buckwheat grown on the sand and clay soils.

With few exceptions, the overall mean metal contents of plant materials fell within the suggested mean levels (Table 5). Buckwheat exhibited somewhat higher levels of Cd and Pb and lower levels of Cr than the other materials. Wheat grain exhibited low levels of Cd and Pb and the straw, low levels of Zn and Cu. Lead levels in all materials except wheat grain were higher than the suggested average and approximated the tolerance level. The lysimeter site is near a major highway and it is probable that wheat grain was the only material to escape contamination with Pb from automobile exhaust. Nickel in orchard grass and wheat grain approximated the tolerance level. The weighted mean Ni content of orchard grass grown on sludge treatments (4.5 µg/g) was much larger than for the NPK treatment (0.9 µg/g). This difference occurred following the application in 1976 of lime sludge from Midland which contained a large amount of Ni. The weighted mean Ni content of orchard grass grown on the high rate of Midland sludge treatment during 1976 was 10.7 and during 1977 was 18 µg/g. The comparable alum and iron sludge treatment data for 1976 were 1.4 and 1.4 µg Ni/g, respectively. Data for Cr and the limited data for Co, Mo and Hg indicated that the levels of these constituents in plant materials approximated the suggested tolerance levels and that there generally were small differences between the control and sludge treatments.

TABLE 4. WEIGHTED MEAN METAL CONTENTS (µg/g dry wt. basis) OF ORCHARD-GRASS GROWN ON LOAMY SAND

Treatment	1973	1974	1975	1976	1973-1976
			Cd		
NPK Control	0.40	0.18	0.12	0.12	0.19
All Sludge Rates	0.54	0.20	0.10	0.21	0.23
High Sludge Rates	0.50	0.21	0.10	0.22	0.22
			Zn		
NPK Control	41	52	45	47	46
All Sludge Rates	47	70	62	64	62
High Sludge Rates	50	92	77	70	74
			Cu		
NPK Control	6.5	7.7	5.2	6.2	6.3
All Sludge Rates	7.4	8.2	7.4	9.8	8.3
High Sludge Rates	8.0	10.0	9.0	10.2	9.4

TABLE 5. A COMPARISON OF THE WEIGHTED MEAN METAL CONTENTS OF PLANT MATERIALS GROWN ON THE HIGH RATES OF FLUID AND AIR-DRIED SLUDGE TREATMENTS WITH SUGGESTED MEAN, TOLERANCE, AND TOXIC CONTENTS (µg/g dry wt. basis)

Constituent	1973-1976 Orchard Grass -Loamy Sand	1974-1976 Wheat Straw -Sand	1974-1976 Wheat Grain -Sand	1975 Buckwheat -Sand	Suggested Mean Levels **	Suggested Tolerance Levels **	Suggested Toxic Levels ***
Cd	0.22	0.17	0.10	0.48	0.05-0.2	3	
Zn	74	24	43	59	15-150	300	>200
Cu	9.4	4.2	8.8	8.7	3-40	150	> 20
Ni*	4.5	1.6	3.1	1.0	0.1-1	3	> 50
Pb	9.6	6.8	0.7	11.5	0.1-5	10	
Cr*	1.9	1.4	2.3	0.7	0.1-0.5	2	
Co*	-	4.0	2.2	-	0.01-0.3	5	
Mo*	1.6	-	-	-	0.2-1	3	
As*	.53	-	-	-	0.01-1	2	
Hg*	.047	-	-	-	0.001-0.01	0.04	

* The Ni, Cr, Mo, As and Hg data for orchard grass and the Co data for wheat straw and grain are mean 1976 only.

** Source: Site monitoring considerations for sludge and wastewater application to agricultural land. P.A. Blakeslee (1976)

*** Source: Fate and effects of trace elements in sewage sludge when applied to agricultural lands. A.L. Page (1974).

Leachate Quality

Weighted mean NO_3-N contents of leachates from the fluid sludge experiment decreased markedly following 1973 and then remained approximately constant with time (Table 6). They increased slightly with sludge application rate but individual values for the high sludge rate treatments were lower for lime than for the alum or iron sludges.

Weighted mean total P contents of the leachates exhibited no consistent differences with increasing sludge rate and time. However, in 1976 leachates from a very few treatments exhibited P concentrations ranging from 1 to 2 mg/L and then in 1977 the values for several treatments ranged as high as 13.2 mg/L. Phosphorus concentrations from May 1976 until October 1977 for the NPK control and the three high rates of sludge treatments on loamy sand soil are illustrated in Figure 3, and indicate the beginning of appreciable P movement. The TOC values exhibited consistent increases with increasing sludge application rate and time (Table 6). Cadmium and Zn exhibited no consistent changes with increasing sludge rate and consistent small increases with time. They were typical of the metal data collected.

The NO_3-N contents of leachates from the air-dried sludge experiment increased with increasing sludge application rate but following a reduction from 1974 to 1975 remained approximately constant (Table 6). Total P and TOC increased with increasing sludge rate. The Cd and Zn data exhibited minor if any changes and were typical of the data for the metals.

The NO_3-N levels in leachates from the fluid sludge experiment approximated the maximum permissible concentration (MPC) for drinking water (Table 7). However, NO_3-N in leachates from the air-dried sludge experiment exceeded the MPC for drinking water, and in leachates from the high sludge application rates greatly exceeded that level. Total P in the leachates was equal to or greater than the drinking water MPC but much lower than the 1 mg P/L standard required for effluents. TOC values approximated the 15 mg/L BOD standard for effluents. Metal concentrations were much lower than the MPC's for drinking and irrigation waters. The conductivities of leachates were much lower than 4 m mho/cm, above which plant growth may be severely restricted.

TABLE 6. WEIGHTED MEAN CONSTITUENT CONTENTS OF LEACHATES FROM THE LYSIMETER EXPERIMENTS (mg/L)

Treatment	Fluid Sludge - Loamy Sand					Air-Dried Sludge - Sand			
	1973	1974	1975	1976	1973-1976	1974	1975	1976	1974-1976
					NO_3-N				
NPK Control	20	4	2	3	10	22	10	22	18
All Sludge Rates	12	3	7	9	9	88	39	61	65
High Sludge Rates	13	6	17	13	13	108	71	79	89
					Total P x 10^2				
NPK Control	2	5	9	50	11	16	13	18	15
All Sludge Rates	5	16	57	27	21	33	14	34	27
High Sludge Rates	9	5	44	23	14	41	8	40	29
					TOC				
NPK Control	6	6	13	11	8	9	14	14	12
All Sludge Rates	7	8	14	21	12	13	38	16	23
High Sludge Rates	8	9	22	23	13	15	34	20	23
					Cd x 10^4				
NPK Control	27	13	16	10	18	11	15	10	13
All Sludge Rates	27	10	18	10	18	13	16	11	14
High Sludge Rates	24	11	18	10	18	15	15	10	14
					Zn x 10^3				
NPK Control	7	13	12	15	11	22	20	37	24
All Sludge Rates	7	12	25	20	15	21	26	22	23
High Sludge Rates	6	13	30	24	14	28	25	21	26

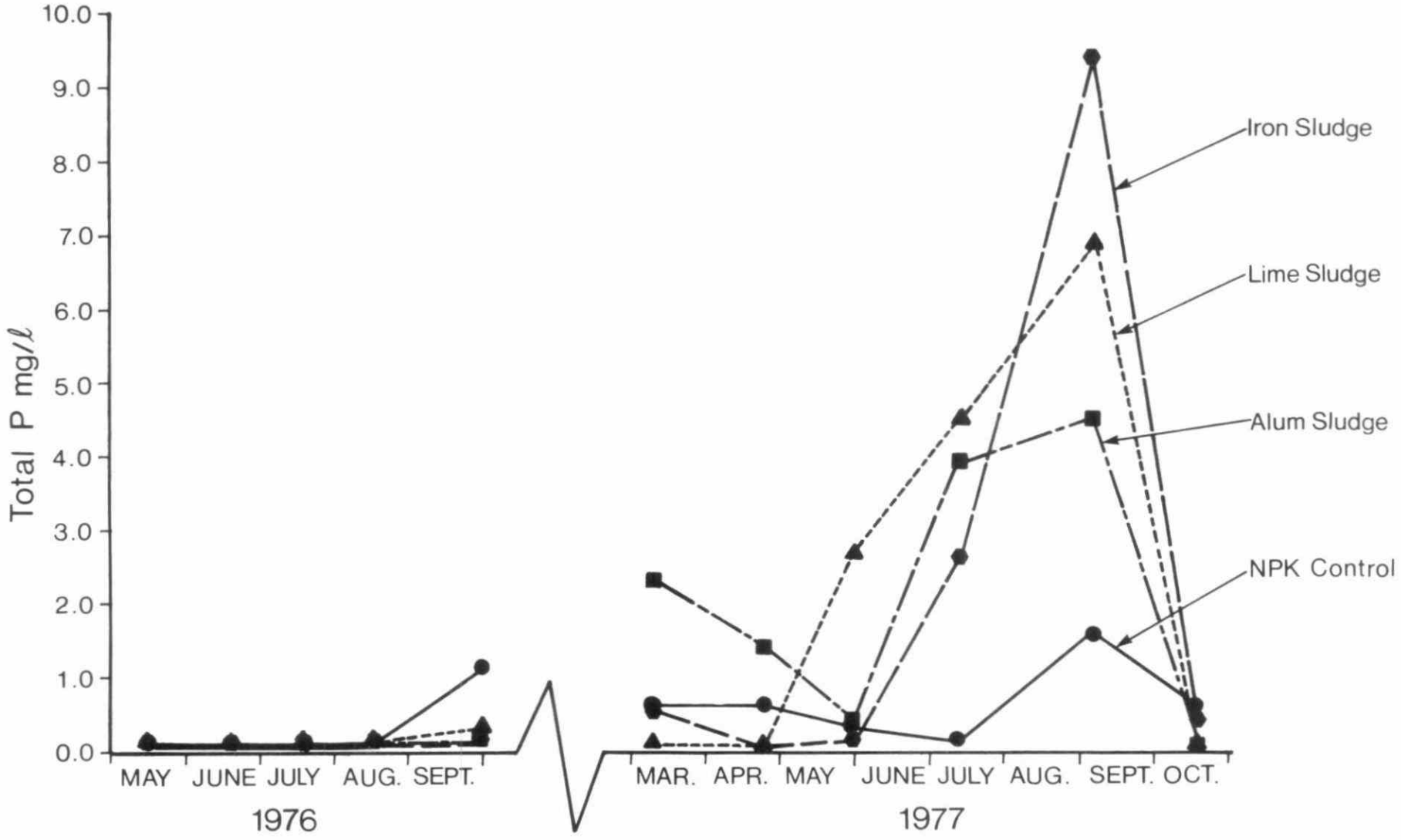


FIGURE 3. Total P concentrations in leachates from the NPK control and high rates of alum, iron and lime sludge treatments.

TABLE 7. A COMPARISON OF THE WEIGHTED MEAN CONSTITUENT CONTENTS OF LEACHATES FROM THE LYSIMETER EXPERIMENTS WITH WATER QUALITY STANDARDS (mg/L)

Constituent	1973 - 1976 Fluid Sludge - Loamy Sand		1974 - 1976 Air-Dried Sludge - Sand		Drinking Water*	Irrigation Water**	Effluent
	NPK Control	High Sludge Rates	NPK Control	High Sludge Rates			
NO_3-N	10.2	13.0	18	89	10.0		
Total-P	0.11	0.14	0.15	0.29	0.1		1***
TOC	7.8	13.2	12.1	22.9			15 (BOD) ****
Cd	0.002	0.002	0.001	0.001	0.01		
Zn	0.011	0.014	0.024	0.026	5		
Cu	0.010	0.013	0.023	0.026	1	5	
Ni	0.004	0.008	0.007	0.006		2	
Pb	0.012	0.013	0.012	0.011	0.05	20	
Cr	0.003	0.004	0.005	0.005	0.05		
Mo	0.001	0.002	0.002	0.002			
As	0.001	0.001	0.001	0.001			
Cond (m mho/cm)	0.54	0.74	0.41	1.0			

* Source: N.H.& W. (1969) Canadian Drinking Water Standards.

** Source: O.M.O.E. (1974) Water Quality Criteria for Agricultural Uses.

*** Source: Canada/U.S. (1972) G.L.W.Q. Agreement - Effluent Requirement.

**** Source: OWRC (1970).

Fate of Sludge and Fertilizer Constituents

Uptake by orchard grass and loss in leachate accounted for appreciable quantities of the N, P, K, Mg and Ca and only minor quantities of the other constituents added to loamy sand soil in fluid sludges and fertilizer (Table 8). Large proportions of the N, P and K added in fertilizer were removed leaving relatively small residues in the soil. Small proportions of the N, P, Mg and Ca added in sludges were removed leaving appreciable residues. More K was removed than was added in sludges. Virtually all of the Fe, Al, Cd, Zn, Cu, Ni, Cr and Pb added in the sludges remained in the soil. There were somewhat larger losses of N, P, Mg and Ca, and approximately equal losses of the other constituents, from the high sludge application rate treatments as from the NPK control. Data for the low and medium sludge application rates were similar to those for the high rates except that the residual values were smaller.

With the few exceptions mentioned below, mass balance data for the air-dried sludge experiment (Table 9) were similar to those for the fluid sludge experiment. Air-dried sludges contributed approximately twice as much P to soil as fluid sludges resulting in more residual P. Wheat/buckwheat took up less N than orchard grass resulting in larger leachate losses and more residual N.

Microbiological Analyses

Leachates from the fluid sludge experiment were monitored monthly from June to November, 1973 for aerobic heterotrophs and various coliform bacteria. After six months of sludge application, no differences in bacterial type or concentration due to sludge treatments were observed. The predominant types of bacteria identified were: Alcaligenes, Acinetobacter, Pseudomonas, Flavobacterium and Chromobacter, which are of soil origin. Bacterial populations in the leachates ranged from 0.1 to 5.5 x 10^6 per ml from all treatments. Apparently the sludge microorganisms were retained in the soils.

After two years of sludge application (2100 kg TKN/ha), the heterotrophic bacteria in leachates ranged from 0.6 to 13 x 10^5 per ml and were only of soil origin.

TABLE 8. MASS BALANCE OF SLUDGE AND FERTILIZER CONSTITUENTS ADDED TO LOAMY SAND SOIL IN THE FLUID SLUDGE - ORCHARD GRASS, LYSIMETER EXPERIMENT, 1973-1976 (kg/ha)

Constituent	Added in Sludge or Fertilizer		Uptake by Plants		Lost in Leachate		Residual	
	NPK Control	High Sludge Rate	NPK Control	High Sludge Rate	NPK Control	High Sludge Rate	NPK Control	High Sludge Rate
N	1836	5100	1381	1652	83	121	372	3327
P	611	3891	129	183	0.9	1.3	481	3707
K	1011 (400)	648 (400)*	923	753	7.6	10.6	80	-116
Mg	-	1828	179	211	116	167	-	1450
Ca	-	58846	376	463	710	1072	-	57311
Fe	-	4402	14.3	16.6	0.40	0.48	-	4385
Al	-	3048	4.0	5.2	0.22	0.31	-	3042
Cd	-	2.7	0.011	0.014	0.014	0.016	-	2.67
Zn	-	325	2.6	4.7	0.09	0.13	-	320
Cu	-	129	0.35	0.60	0.08	0.12	-	128
Ni	-	106	0.01	0.08	0.03	0.06	-	106
Cr	-	80	0.02	0.08	0.03	0.03	-	80
Pb	-	121	0.42	0.58	0.10	0.11	-	120

* 400 kg K/ha as muriate of potash was applied to the NPK control and all sludge treatments.

TABLE 9. MASS BALANCE OF SLUDGE AND FERTILIZER CONSTITUENTS ADDED TO SAND SOIL IN THE AIR-DRIED SLUDGE - WHEAT/BUCKWHEAT, LYSIMETER EXPERIMENT, 1974-1976 (kg/ha)

Constituent	Added in Sludge or Fertilizer		Uptake by Plants		Lost in Leachate		Residual	
	NPK Control	High Sludge Rate	NPK Control	High Sludge Rate	NPK Control	High Sludge Rate	NPK Control	High Sludge Rate
N	420	5252	396	453	130	639	-106	4160
P	360	7641	59	68	1.1	2.1	300	7571
K	360	208 (60)*	277	175	14.1	15.1	69	18
Mg	-	1065	54	71	70	169	-	825
Ca	-	44295	139	180	382	1274	-	42841
Fe	-	5038	5.07	5.05	0.31	0.54	-	5032
Al	-	4326	1.82	1.32	0.75	0.62	-	4324
Cd	-	2.60	0.010	0.005	0.009	0.010	-	2.58
Zn	-	224	0.97	0.86	0.17	0.18	-	223
Cu	-	120	0.13	0.15	0.16	0.18	-	120
Ni	-	3.5	0.05	0.05	0.05	0.05	-	3.4
Cr	-	38	0.03	0.03	0.04	0.04	-	38
Pb	-	110	0.18	0.14	0.09	0.08	-	110

* 60 kg K/ha as muriate of potash was applied to all sludge treatments.

Soil analyses following application of 900 (April, 1974) and 5100 (July 1977) kg TKN/ha in fluid sludges indicated that most of the heterotrophic bacteria (>90%) were retained in the top 15 cm layer of both the loamy sand (Figure 4) and silt loam soils. The population densities of all but the surface soils were less than or equal to the normal range for untreated surface soils. It was calculated that 90%-98% of the heterotrophic bacteria added to soil in fluid sludge up to July, 1977 had died.

No microbiological analyses have been done for the air-dried sludge experiment.

DISCUSSION

Lysimeter Experiments

Fluid and air-dried sludges supplied N, P, Ca, Mg and micro-nutrients for crop production. However, they were deficient in K and it was necessary to use potash fertilizer as a supplement.

There was no evidence that the aluminum, iron and lime added to sewage for phosphorus removal caused crop production problems. Cumulative orchard grass yields appeared to be related to nitrogen availability. The medium fluid sludge application rates supplied approximately twice as much TKN and produced about the same yields as the NPK fertilizer treatment. Annual orchard grass yields increased from 1973 to 1975 and then decreased markedly from 1975 to 1977. These trends occurred for both sludge and fertilizer treatments. Cumulative wheat/buckwheat yields from clay soil exhibited no differences between air-dried sludge and fertilizer treatments but from sand soil, the iron and lime sludges produced lower yields than alum sludge or NPK fertilizer. The wheat/buckwheat crop yields varied widely from year to year but these variations were evident for all treatments.

Applications of air-dried sludges to soils (Table 2) in a few large increments resulted in nitrogen availability far in excess of crop requirement. Leachates from the air-dried sludge treatments contained much more than the 10 mg NO_3-N/L, MPC for drinking water. Similar applications of fluid sludges, applied in several smaller increments, generally resulted in leachates with $\leq$ 10 mg NO_3-N/L. Mass balance

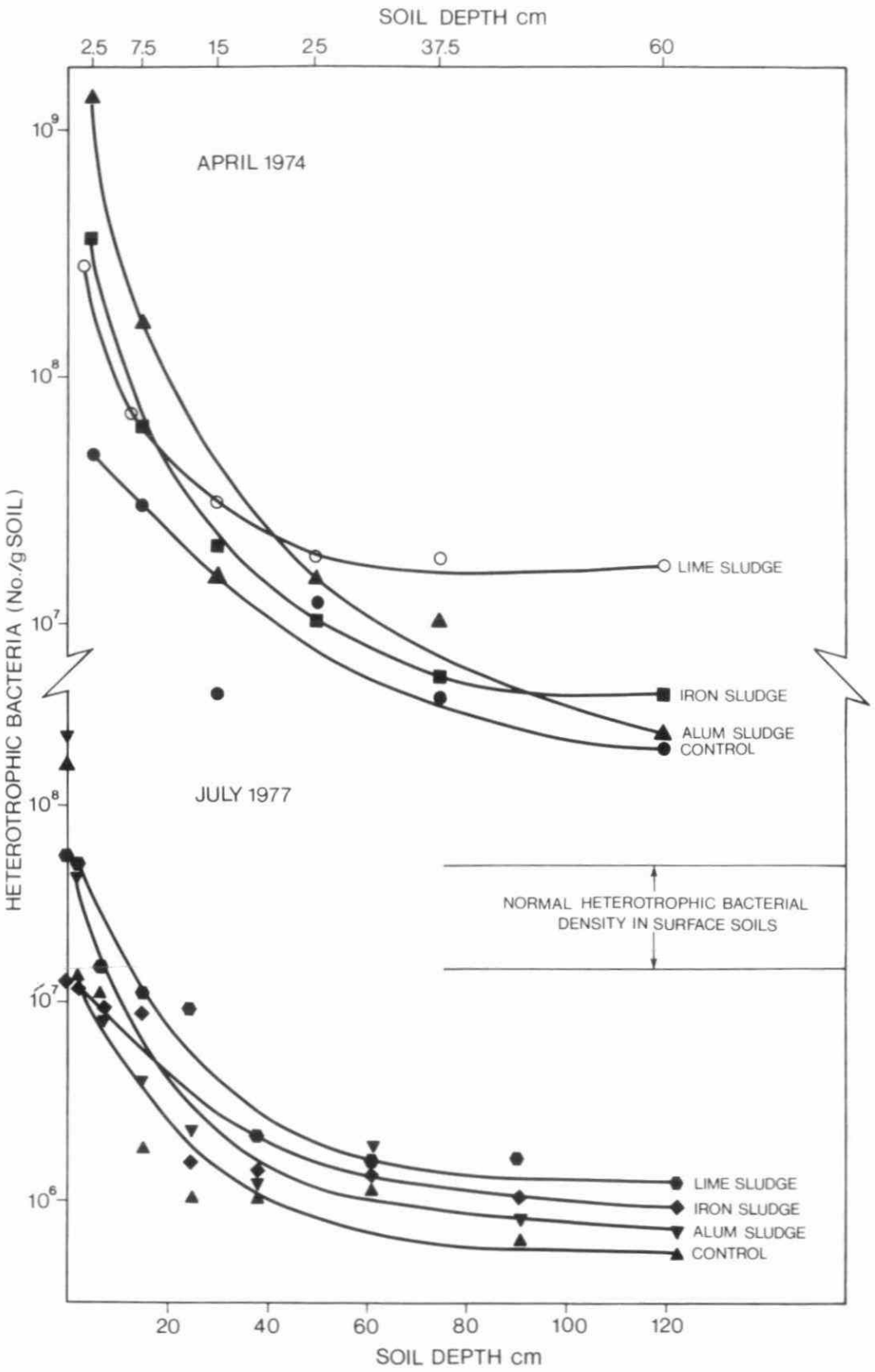


FIGURE 4. HETEROTROPHIC BACTERIA IN LOAMY SANDY SOIL APRIL 1974 and JULY 1977.

calculations for both types of sludge indicated that large residues of nitrogen remained in the soils. No account was taken of possible losses due to denitrification.

Almost all of the phosphorus in sludges remained in the soils. Crop uptake accounted for very little and leachate losses were insignificant. Leachates from the air-dried sludge experiment exhibited concentrations generally larger than the 0.1 mg P/L MPC for drinking water but smaller than the 1 mg P/L MPC for sewage effluent. Leachates from the fluid sludge experiment exhibited a similar range of concentrations until 1975 but then in 1976 concentrations of 2 and 3 mg P/L and in 1977 concentrations > 10 mg P/L were observed. The authors are unable to explain this phenomenon. Increased levels in leachate would be expected to occur following soil saturation with P. However, measurements of plant available P ($NaHCO_3$-soluble) for the NPK and high sludge treatments indicated that almost all of the added phosphorus remained in the surface 5 cm of soil and none moved below 10 cm. Soil-test P at the surface of the NPK and high alum, iron and lime sludge treatments was 56, 125, 180 and 815 µg/g soil, respectively, and far exceeded the value of 20 µg/g soil considered adequate for corn production in Ontario (OMAF, 1978).

The high sludge application rates employed in the lysimeter experiments supplied Cd, Zn, Cu, Pb, Mo and Hg in approximately the amounts recommended as maxima for Ontario agricultural land. The Ni, except for lime sludge, and Cr and As additions were generally smaller than the recommended maxima. The high rates of air-dried sludges applied during 1974 contained 18 times the recommended annual "zinc equivalents" loading to soils in England (Chumbley, 1971). Despite these heavy loadings, metal levels in leachates from the lysimeter experiments were smaller and usually much smaller than the levels defined in standards for drinking and irrigation waters. Moreover, the metal contents of crops grown on the sludged soils were generally smaller than or equal to suggested tolerance levels (Blakeslee, 1976). Nickel was the only metal which far exceeded the tolerance level in any crop. Orchard grass exhibited levels of 10 and 18 µg Ni/g in 1976 and 1977, respectively, following the addition of lime sludge from Midland which contained 2530 µg Ni/g dry wt.

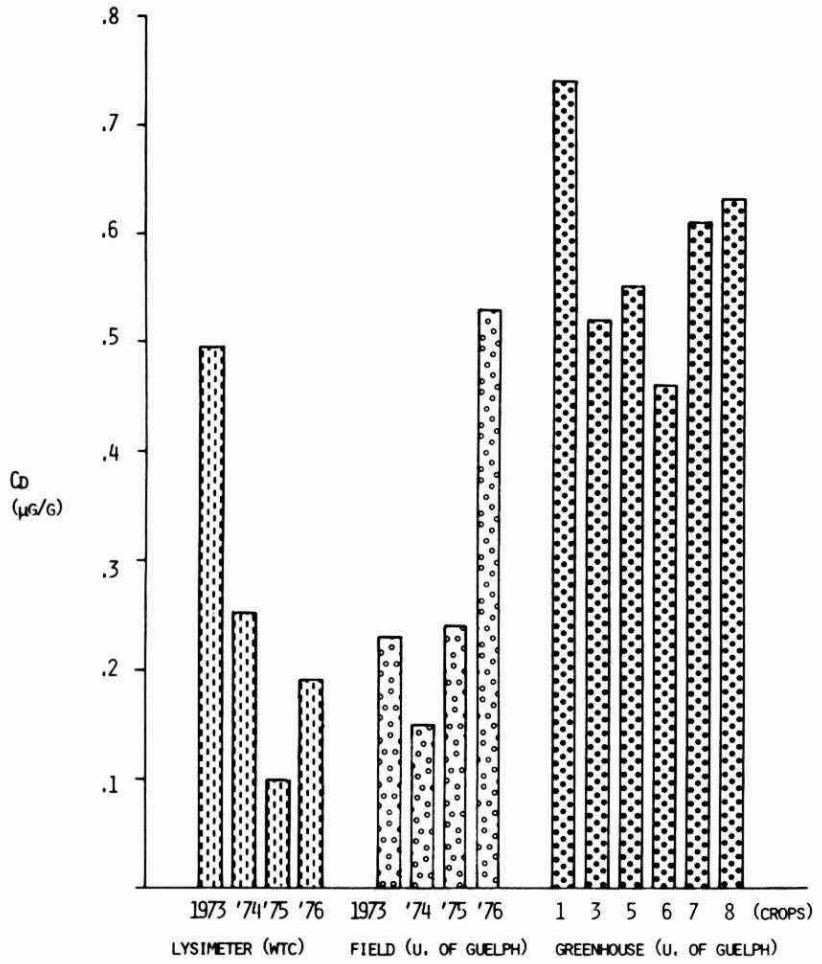
Limited microbiological studies indicated that microorganisms in the liquid sludges were retained and died in the surface 15 cm layer of soil.

The high rates of fluid and air-dried sludge applications to the lysimeter experiments were equivalent to average annual rates ranging from 29 to 76 and 43 to 142 tonnes/ha dry wt., respectively. These rates are extreme and very much larger than the 2 tonnes/ha average annual rate for Ontario farmland. Low metal concentrations in leachates and low or tolerable metal contents in plant materials from these treatments indicated that metals may be a less serious risk related to sludge application on agricultural land than was thought prior to beginning experimentation in 1973. However, large NO_3-N losses in leachate and excessive P application to soils confirmed that additions of these nutrients should be regulated as suggested in the OMAF/OMOE (1976) guidelines for sludge use. Land application of sludge to provide efficient crop use of N and P would limit metal additions to acceptable levels for many Ontario sludges.

Comparison of WTC Lysimeter, and U. of Guelph Field and Greenhouse Data

Orchard grass grown in lysimeters, bromegrass grown in the field, and ryegrass grown in the greenhouse following sludge treatments provide a comparison of metal contents in plant materials. The lysimeter and field experiments employed the same time frames, soils and where possible the same sludge sources. Metal loadings to the lysimeter and field experiments were similar for the iron and lime sludges and for all except Ni and Cr in alum sludges. The Ni and Cr loads in alum sludge were 11.3 and 35 times greater for the field experiment. The greenhouse study employed much larger loading rates of metals than the lysimeter and field studies.

The Cd data showed no definite trends with time (Figure 5). Lysimeter values declined with time to 0.10 µg Cd/g in 1975 and then increased to 0.19 µg/g in 1976. Field results at the end of the third year were virtually identical with the first year but then increased sharply in 1976. Greenhouse results declined between the first and sixth crop to 0.46 µg/g. Deviation of Cd from NPK control values never exceeded +0.10 µg/g in either lysimeter or field tests. Although



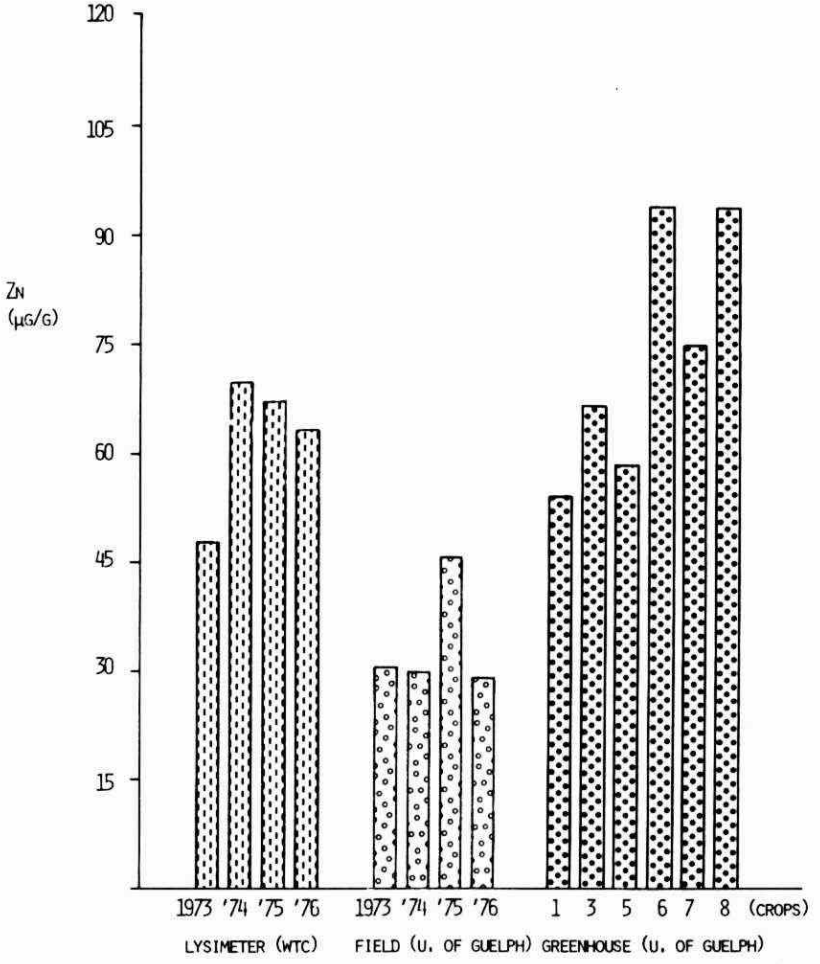


Figure 5 MEAN Cd AND Zn CONCENTRATIONS IN GRASSES FROM THE HIGH SLUDGE RATE TREATMENTS OF LYSIMETER, FIELD AND GREENHOUSE EXPERIMENTS.

absolute values of Cd tended to reflect the relative loading of this metal in each experiment, all values were well below the 3 µg Cd/g maximum suggested tolerance level (MTL).

Zinc concentrations in plant tissues showed a slight tendency to increase over time in the lysimeter and field studies and a more pronounced tendency to increase in the ryegrass greenhouse experiment (Figure 5). High Zn uptake in ryegrass grown in the greenhouse was observed (Soon, 1977) for a heavily metal contaminated sludge from Sarnia, Ontario. Although the maximum concentration in this crop (320 µg Zn/g) exceeded the suggested MTL of 200 µg/g, no yield depression was observed. As zinc has been implicated in the literature as being highly toxic to many plants, this metal should continue to be monitored in orchard grass and bromegrass for at least a decade despite the fact that information obtained to date does not indicate any immediate cause for concern.

Copper concentrations showed a tendency to increase with time (Figure 6). However, the highest average annual values for both lysimeter and field studies were below the MTL of 20 µg Cu/g. The sixth ryegrass crop value, however, exceeded the suggested MTL. Deviations from NPK control values never exceeded +5 µg/g in the lysimeter study, and declined in the 1975 field study to <+2 µg/g. High Cu concentrations in ryegrass grown on a soil receiving unusually large metal additions in Fergus sludge have been implicated as the cause of crop yield depression (Bates et al, 1977). Yield depression has not been observed to date at the highest loading rates of Cu to either the lysimeter or field crops. However, cumulative sludge application up to the loading applied with the Fergus sludge is required to determine whether Cu toxicity can be induced in forage crops following repeated applications of fluid sludge to the same site.

Average Ni concentrations ranged between 0.9 and 4.35 µg/g in the lysimeter experiment and 1.0 to 1.9 µg/g in the field experiment (Figure 6). The large increase observed for the lysimeter experiment in 1976 was due to application of Midland sludge which produced plant material with 10 µg Ni/g. Although Ni concentration appeared to increase over time in the field results, recent information from the University of Guelph

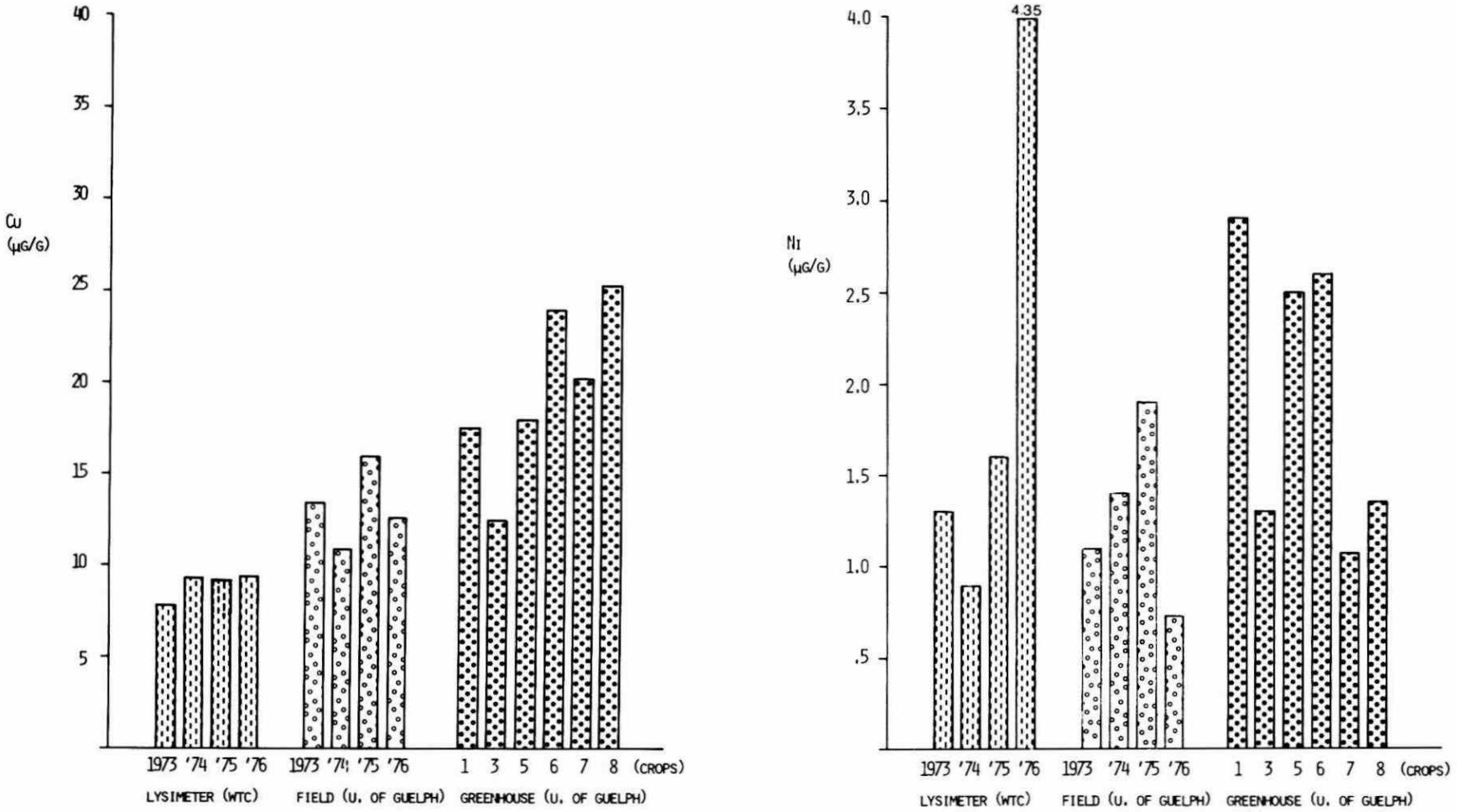


Figure 6 MEAN Cu AND Ni CONCENTRATIONS IN GRASSES FROM THE HIGH SLUDGE RATE TREATMENT OF LYSIMETER, FIELD AND GREENHOUSE EXPERIMENTS.

(Soon, 1977) indicates that the nickel concentration in the 1976 bromegrass crop (third cut) declined to less than 1.0 µg/g. The MTL for nickel is 3.0 µg/g; however, concentrations as high as 47.0 µg/g in ryegrass grown in the greenhouse experiment showed no yield depression. In view of this information, nickel toxicity is not considered to be a problem for the three crops investigated in these experiments.

Lead is the only metal whose concentration is greater in plant tissue from the lysimeter than the field or greenhouse experiments (Figure 7). The deviations from NPK control values are less than +2 µg/g in the lysimeter studies and less than +1 µg/g in both field and greenhouse studies. In view of previous comments concerning absorption of lead from automobile exhaust by plants growing near major highways, and the reported low uptake of lead by most agricultural crops, this element is not considered a cause for concern for the crops grown in these experiments.

Chromium data exhibited no consistent trends and fluctuated between 0.6 and 1.75 µg/g in the lysimeter experiment, and 0.8 to 2.4 µg/g in the field experiment (Figure 7). Greenhouse values were not reported for the third and fifth cut as there were no significant differences between treatments. Deviations from NPK control values were generally low, rarely exceeding +0.30 µg/g. In view of its minimal toxicity to plants and animals and evidence of deficiency in the human diet (Underwood, 1971) the Cr levels observed in the grasses were not considered to be a cause for concern.

The comparison of data indicates that the lysimeter, field and greenhouse experiments produced similar results. Sludge metal loadings to the greenhouse experiment were larger than to the lysimeter and field experiments. Except for Pb, metal contents in the three different grasses were generally related to sludge metal loadings.

Future Plans for the Lysimeter Experiments

Metal levels in forage and cereal crops grown following the high rates of sludge applications were not considered to be a serious cause for concern related to sludge use on agricultural land. However, it is well established that these crops accumulate smaller amounts of

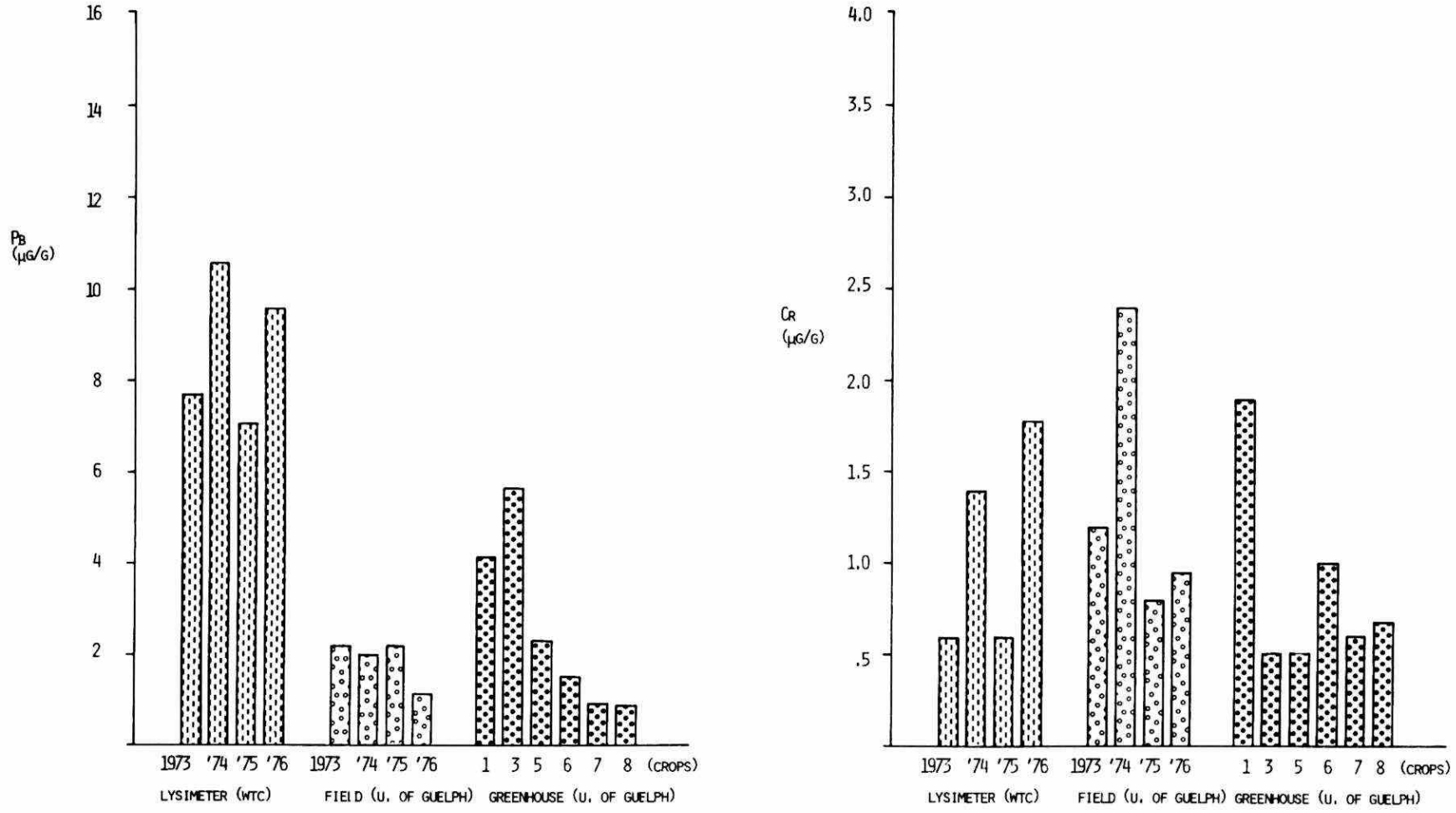


Figure 7 MEAN Pb AND Cr CONCENTRATIONS IN GRASSES FROM THE HIGH SLUDGE RATE TREATMENTS OF LYSIMETER, FIELD AND GREENHOUSE EXPERIMENTS.

metals than leafy vegetables such as swiss chard, spinach and lettuce. Beginning in 1978, swiss chard will be grown in several replicates of both the fluid and air-dried sludge, lysimeter experiments. In addition, the present crops with and without sludge application will continue to be grown and the experiments will be expanded to include an acid sand soil. The present soils are approximately neutral in pH. Measurements will be made to determine whether sludge metals added to the lysimeters to date have moved down the soil profile. Metal solubilities will also be determined. Efforts will be made to identify the organic materials which appeared as high TOC values in leachates.

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CONCEPTS OF SLUDGE UTILIZATION ON AGRICULTURAL LAND

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INTRODUCTION

Wastewater treatment was initiated to reduce pollutional inputs of liquid waste discharges to receiving waters. At the outset, the prime function of a wastewater treatment plant was to remove settleable solids from incoming municipal sewage prior to the release of the effluent into the nearby stream. The solids removed from this operation were often indiscriminately disposed of in the environment. Traditionally, efforts in wastewater treatment improvements have been directed towards effluent quality with little consideration given to the treatment and disposal of the by-product of this operation - sewage sludge. Today, wastewater treatment has developed into a highly efficient physical, chemical, and biological process providing for nutrient (phosphorus), biochemical oxygen demand and solids removal prior to discharging the effluent into receiving waters. Secondary sewage treatment for example, achieves a significant reduction in suspended and settleable solids. Typically, a final effluent is produced with a suspended solids range of 10 to 30 mg/L from influent raw sewage having a suspended solids range of 100-350 mg/L. With the continual upgrading of effluent quality, undesirable contaminants are being concentrated in the sludge and the disposal of this material in an environmentally acceptable manner is becoming more and more cumbersome. This paper briefly discusses sludge treatment and disposal practices in the Province of Ontario. Emphasis is given to describing the concept of sewage sludge utilization on agricultural land. Based on such a concept, guidelines have been developed to control the sludge spreading operations. These guidelines, however, have not yet been adopted officially by the Ontario Government.

CURRENT SLUDGE PRODUCTION AND DISPOSAL PRACTICES IN ONTARIO

There are some 349 sewage treatment works in the Province of Ontario. An estimated 210 are mechanical primary and secondary plants with 67% of these providing secondary treatment. Lagoons account for the remaining 139 sewage treatment facilities. The four Metropolitan Toronto sewage treatment installations have a combined design capacity of some 300 million gallons per day. The Ashbridges Bay Toronto Plant, the largest plant in Ontario has a design capacity of 200 Imgd. Of the remaining wastewater treatment plants, 71% have a design capacity equal to or less than 2 Imgd, while only 6% have a design capacity greater than 10 Imgd.

Sludge disposal practices in Ontario (1977) are estimated as follows (data extrapolated from a 1975 Sludge Disposal Practices Survey):

Method of Disposal	Amount of Sludge (dry tons/year)	% of Total
Incineration	70,006	39.8
Application to agricultural land	59,754	34.0
Disposal by landfill	39,513	22.5
Disposal by other means (lagooning, drying and stockpiling for use in home gardens, etc.).	6,512	3.7
	175,785	100.0

Sludge disposal practices presently in use at the 210 mechanical plants in Ontario are summarized as follows (data extrapolated from a 1975 Sludge Disposal Practices Survey):

Disposal Practice	No. of Mechanical Treatment Plants	% of Total
Application to Agricultural land	133	63.2
Disposal by Landfill	23	11.0
Dumpsite plus mine tailings	19	9.0
Lagooning (storage)	10	4.5
Incineration	3	2.0
Drying Beds	22	10.3
Total	210	100.0

Sewage sludges are highly variable in physical and chemical composition. The solids, nutrient or metal content of the sludges can vary dramatically depending upon the origin of the waste, the level of industrial activity in the community, the type of treatment process, and the individual method of plant operation (digester design and operation, etc.). Variations have been reported to occur not only from one municipality to another but also from day to day in the same municipality.

Table 1 gives the range of concentration of various constituents in liquid sewage sludge produced from 37 Ontario municipalities. Capacities of plants surveyed range from 0.13 to 37.5 Imgd, with 67% of the plants having design capacities of less than 4 Imgd. Types of treatment include primary treatment (nine plants), conventional secondary treatment (22 plants), and extended aeration (six plants).

PHOSPHORUS REMOVAL IN ONTARIO

Following a six-year study of boundary water pollution, the 1969 International Joint Commission Report [10], recommended the reduction, to the lowest practical level, of phosphorus discharges from all sources in the Lower Great Lakes drainage basin. In response to this, the Province of Ontario announced a policy requiring the installation of phosphorus removal facilities at municipal and institutional wastewater treatment plants not only in the Lower Great Lakes, but also in parts of the Upper Great Lakes, the Ottawa River system and inland recreational areas.

Permanent phosphorus removal facilities capable of producing effluent total phosphorus concentrations not exceeding 1 mg/L in the Lower Great Lakes, and 80% removal of total phosphorus in other areas, were to be operational in high and medium priority areas by December 31, 1973 and December 31, 1975, respectively. In addition, phosphorus removal could be requested in areas of the Province where problems were found to exist. Table 2 gives the total number of wastewater treatment plants with phosphorus removal facilities operational, as of 1976 and of 1977.

Phosphorus removal in Ontario involves a chemical precipitation process in which aluminum or iron salts are used as the prime coagulants.

TABLE 1.

Range of Concentrations of Various Constituents in Liquid Sewage Sludge Produced from 37 Ontario Municipalities (Data based on Ontario Ministry of the Environment 1974. Operating Summary [15]).

	CONSTITUENT	RANGE*	MEAN*
1.	Total Solids (%)	1.7 - 17.1	4.8
2.	Total Kjeldahl N.	2.3 - 9.3	3.8
3.	Ammonia N.	0.15 - 4.2	0.9
4.	P	0.68 - 5.6	2.3
5.	Zn	4 - 210	54.6
6.	Cu	7 - 150	37.7
7.	Ni	0.4 - 254	14.1
8.	Pb	3.7 - 99	21.7
9.	Cd	0.1 - 570	18.2
10.	Mn	0.3 - 65	15.8
11.	Fe	45 - 7600	944
12.	Ca	331 - 11,000	2275
13.	Mg	100 - 1400	337
14.	Co	0.3 - 110	4.1
15.	Hg	0.0001 - 0.4	0.05
16.	Mo	0.2 - 50	4.9
17.	Ti	17 - 218	75.6
18.	Cr	0.3 - 430	41.9
19.	Al	100 - 2700	580
20.	Cl^-	27 - 830	163
21.	Alkalinity (as CaO_3)	323 - 2600	5218
22.	Na	4.5 - 230	66.1
23.	K	2 - 119	43.9

* Range and mean for constituents 2 to 4 are given in percent of dry sludge solids; for constituents 5 to 23, range and mean are expressed in ppm as sampled.

TABLE 2. PROVINCE OF ONTARIO PHOSPHORUS REMOVAL PROGRAM*

BASIN	TOTAL NUMBER OF TREATMENT PLANTS WITH PHOSPHORUS REMOVAL IN OPERATION IN 1976	TOTAL NUMBER OF TREATMENT PLANTS WITH PHOSPHORUS REMOVAL IN OPERATION IN 1977
Lake Superior	0	0
Lake Huron	31	37
Lake Erie	66	80
Lake Ontario - St. Lawrence	62	77
Ottawa River	9	17
Total	168	211

* Data summarized from Summary Report of the Phosphorus Removal Program, April 1976 [16] and from Ontario Ministry of Environment Management Information and Analysis System.

Lime is also being utilized as an alternative at some locations. These chemicals, when added to the sewage treatment process, tend to increase the weight of solids produced, increase the volume of sludge to be disposed of and alter its composition. Along with their ability to precipitate phosphorus, the coagulants tend to remove greater quantites of heavy metals from solution, affect the nitrogen fraction of the sludge, and produce a sludge that is more chemical in nature. Consequently, phosphorus removal has increased the concern with regard to the acceptability of chemical sludges for application to agricultural lands.

SLUDGE DISPOSAL COSTS

Land application has proven to be the most common method of sludge disposal for the majority of Ontario localities because of the large number of relatively small treatment and disposal operations involved. Sludge haulage costs for land application can vary a great deal and are very much dependent on the haulage distance, the size of the haulage vehicle and the percent solids in the sludge being hauled. Sludge haulage costs (1975) for land application of liquid digested sludge range from 14.1 to 93.6 dollars per ton dry solids with an average cost of about 53.8 dollars per ton dry solids [15]. Taking inflation into account, current average cost is estimated to be approximately 67 dollars per ton dry solids.

SEWAGE SLUDGE - UTILIZATION OR DISPOSAL?

As previously mentioned, land application has become the most common method of sludge disposal in Ontario; however, in the past it has been a disposal as opposed to a utilization practice. Disposal invariably leads to accumulation of undesirable compounds in air, soil or water which have a potential for detrimentally affecting our environment. In recent years, however, the attitude towards sludge has changed considerably; it is now looked on as an excellent and economic source of valuable nutrients that can be effectively utilized by the agricultural community. In keeping with the overall concept of re-use, recycling and waste reclamation, the Ontario Ministry of the Environment (MOE) is encouraging the optimum utilization of sewage sludge on agricultural lands. In addition, MOE in conjunction with the Ontario Ministries of Agriculture

and Food (OMAF), and Health (MOH) have been formulating research strategy and evaluating the results in a continuing effort to determine the suitability and to provide guidance with respect to the utilization of sewage sludge on agricultural lands.

AGRICULTURAL VALUE OF SEWAGE SLUDGE

From the agricultural standpoint sewage sludge has long been recognized as a soil builder or conditioner and as a fertilizer supplement. As a soil conditioner, digested sewage sludge improves the physical properties and generally enhances the productive capacity of the soil. As a fertilizer supplement, sewage sludges contain variable, but significant amounts of the major plant nutrients. "Typical" sewage sludge (Table 1) contains about 3.8% by weight total Kjeldahl nitrogen, and 2.3% by weight phosphorus. Sewage sludges also contain lesser quantities of potassium and virtually all other nutrients essential for plant growth.

The potential nitrogen, phosphorus, potassium and organic matter value of the sludge currently spread on farmland, if fully utilized in agricultural production (some 59,754 dry tons of sludge per year or 34.0% of the total sludge produced) is estimated to be in excess of 1.2 million dollars per year. Alternatively speaking, the equivalent fertilizer value of sewage sludge is approximately $21 per ton of dry solids (based on 1976 fertilizer prices and including the sludge value as a soil amendment).

EXISTING REGULATIONS FOR SEWAGE SLUDGE APPLICATION TO AGRICULTURAL LANDS

Under amendments to Ontario Regulation 824, made under the Waste Management Act (now under the Environmental Protection Act, 1971), the "processed organic waste" program has been established to control the application of sewage sludges to agricultural lands. These Regulations prescribe standards for the location, maintenance and operation of "organic soil conditioning sites" which can receive "processed organic wastes" from sewage treatment plants. Under this program, a contractor engaged in hauling and spreading sludge on agricultural lands must have a Certificate of Approval for his sludge handling system. This certificate covers the hauling vehicle as well as the spreading equipment. In

addition, Certificates of Approval are necessary for all sites receiving sludge from a particular sewage treatment plant.

Certificates of Approval for both the system and site(s) are required before any contractual arrangement can be made between the sludge hauler and the sewage treatment plant operating authority. Procedures have been established in obtaining Certificates of Approval for both the system and site(s) (Appendix).

THE ROAD TO UTILIZATION

The concept of utilizing or recycling sludge nutrients on agricultural land is not only feasible but, in light of the current and future need for resource and energy conservation, this approach is also desirable. However, before we can embark on the road to utilization, a number of problems must be addressed and suitably resolved. Problems associated with the land application of sludge include:

- public health hazard,
- nutrient enrichment of surface and groundwater,
- heavy metal addition,
- site selection.

Public Health Hazard

When consideration is given to land application of sewage sludge, potential health hazards are of major concern. Ensuring that only processed sludge is applied to agricultural land will greatly minimize the public health implications. Sludge can be processed by aerobic or anaerobic digestion or by other means of stabilization (lime stabilization, etc.). Anaerobic digestion is a widely used sludge treatment process and it has the ability to reduce and stabilize the organic matter in sludge, eliminate odour potential, and destroy a large number of pathogenic organisms.

When sewage sludge is applied to land, adequate contact time in the soil matrix is required to inactivate bacterial and viral pathogens surviving the digestion process. Inactivation occurs by adsorption, attack by soil bacteria, natural dieoff, etc. and is primarily dependent on the nature of the soil, moisture, pH and temperature [7].

Parasitic organisms (flatworms and roundworms) are of particular concern in land application systems because sewage treatment processes have little effect on the viability of parasitic ova. Most parasitic organisms present in the incoming sewage move from the wastewater to the sludge where the ova may remain viable. In the soil, parasitic ova, protected by their cysts, may remain viable for many months.

Because of the risk of survival of bacterial and viral pathogens and, in particular, parasitic organisms, the current thinking in Ontario is that processed sludge may be utilized in agricultural production provided that the land is not used to grow fruit and vegetables or for sheep and swine pasturing within six months after sludge application. For horses, dairy and beef cattle, the grazing limitation is reduced to two months after sludge application.

Nutrient enrichment of surface and groundwater

Crop selection and sludge application rate require special consideration in order to minimize ground and surface water contamination problems. The crops best suited to use the nitrogen in sewage sludge are corn for grain or silage, grass for hay and commercial sod. Other crops that could receive sewage sludge but which would not fully utilize the nitrogen are soybeans and legumes or legume-grass pasture and hay. In terms of application rates, the nutrient addition via the sludge should be closely related to the nutrient requirement of the crop.

Although nitrogen is an essential crop nutrient, if applied to soil in excess of plant requirement, it may lead to crop lodging and thus reduce the value of the crop. In addition, high rates of sludge application may cause nitrate enrichment in the groundwater, and through runoff, may lead to surface water contamination.

Phosphorus is also required for healthy crop growth; however, only the small dissolved fraction of the total soil phosphorus is available for crop use. Soluble phosphorus added to the soil system is converted to forms that are relatively insoluble within a short period of time. Phosphorus in sludge is primarily in organic forms and biological mineralization through normal decomposition processes generally occurs slowly [7]. Therefore, phosphorus leaching into the groundwater is of

minor concern; however, if the soil phosphorus level is permitted to build-up, phosphorus contamination of receiving streams as a result of soil erosion and surface runoff may occur.

Ongoing studies at the University of Guelph suggest that sewage sludge increases the soluble (plant available) phosphorus level in soil quite markedly [1]. Also, studies at the University of Illinois indicate that excessive amounts of phosphorus added to soil in sewage sludge may induce nutrition imbalance in plants such as soybean [19].

To preclude ground and surface water contamination and to control the rate of accumulation of phosphorus and metals in soil, it is suggested that the rate of application of sewage sludge should not exceed the equivalent of 120 lb of ammonium plus nitrate nitrogen per acre over a five-year period. Sludge application rate has been based on ammonium plus nitrate nitrogen because these forms of nitrogen are readily available for crop use. If sludge is to be utilized in commercial sod production, the frequency of sludge application can be increased to every four years or the equivalent over a four-year period. The restriction of 120 lb every four years for commercial sod and every five years for other crops is not set to restrict nitrogen application. This restriction is set to control the rate of accumulation and to provide a wider distribution of the phosphorus and some of the metals in soil, and to facilitate their utilization by crops. It also allows some lead time to find out more about the impact of metals before the soils are contaminated significantly. All Ontario sludges tested appear to be high in phosphorus and one application supplying 120 lb ammonium plus nitrate nitrogen per acre will also supply enough phosphorus for crop needs for at least five years even on soil low in phosphorus. If any use is to be gained from copper, zinc, selenium and cobalt then sludges must be widely distributed and not concentrated on a few fields or farms. Application of sludge to one field, year after year, becomes a disposal and not a utilization practice.

The most efficient use of phosphorus will be obtained when a soil test is used as a guide for sewage sludge application. Sewage sludge should be applied only to those fields on which the soil test indicates a phosphorus requirement for the crops to be grown. For

example, a sodium bicarbonate soil test of 21 ppm phosphorus is the point at which no further phosphorus addition is recommended, if the crop to be grown is corn. It is suggested that sewage sludge not be applied to soils on which the sodium bicarbonate soil test (a measure of the plant available phosphorus) is 60 ppm phosphorus or greater in the top six inches.

Heavy Metal Addition

Metals present in municipal wastewater are attributed to industrial discharges, as well as other diverse sources such as water pipes and tanks, toilet preparations, food washing, surface runoff in combined sewers, human wastes, etc. The sewage treatment process greatly concentrates the metals in the sludge and the addition of this sludge to agricultural lands is the cause of considerable concern.

When sludge is applied to agricultural land the metals present may have detrimental effects on ground and surface water systems, soil, crop and higher food chain because of:

- metal build-up in soil,
- metal effect on plant growth,
- metal uptake by plants and subsequent transfer to animals and humans,
- surface water contamination via erosion and surface runoff,
- groundwater contamination via leaching following long-term metal build-up in the soil.

A two-fold approach involving maximum allowable metal concentration in soil and acceptable sludge quality is currently being considered to control the level of heavy metal accumulation in soil and crop, and to ensure that soil metal levels do not build up to excessive proportions. This concept is summarized in Table 3.

Metals that are likely to approach critical levels under Ontario conditions are arsenic, cadmium, cobalt, chromium, copper, mercury, molybdenum, nickel, lead, selenium and zinc (Table 3, column 1). Mean metals concentrations of uncontaminated Ontario soil are given in Table 3, column 2 and have been based on a survey of metals levels in agricultural soils conducted by the Ontario Ministry of Agriculture and Food.

TABLE 3. METAL CRITERIA FOR SEWAGE SLUDGE APPLICATION

1	2	3	4	5	6	7
				PHASE I		PHASE II
METAL	MEAN METAL CONTENT OF UNCONTAMINATED ONTARIO SOILS (ppm)	MAXIMUM RECOMMENDED METAL CONTENT IN SOIL (ppm)	MAXIMUM RECOMMENDED METAL ADDITION TO SOIL (lb/A)	MINIMUM AMMONIUM PLUS NITRATE NITROGEN (NH_4^+-N PLUS NO_3^--N) TO METAL RATIOS REQUIRED IN SEWAGE SLUDGE	NUMBER OF SEWAGE SLUDGE APPLICATIONS TO GIVE MAXIMUM RECOMMENDED METAL CONTENT IN SOIL (COL. 3)*	AMMONIUM PLUS NITRATE NITROGEN (NH_4^+-N PLUS NO_3^--N) TO METAL RATIOS REQUIRED TO GIVE MAXIMUM RECOMMENDED METAL CONTENT IN SOIL (COL. 3) IN 50 APPLICATIONS
ARSENIC	6.5	13	13	100	10	500
CADMIUM	0.7	1.4	1.4	500	5	5000
COBALT	4.5	18.0	27.0	50	10	250
CHROMIUM	14.0	112	196	6	10	30
COPPER	25.0	100	150	10	10	50
MERCURY	0.08	0.5	0.8	1500	10	7500
MOLYBDENUM	0.4	1.6	2.4	250	5	2500
NICKEL	16.0	32	32	40	10	200
LEAD	14.0	56	84	15	10	75
SELENIUM	0.4	1.6	2.4	500	10	2500
ZINC	54.0	216	324	4	10	20

* Based on 120 lb ammonium plus nitrate nitrogen per application and sewage sludge having minimum ratios. Number of applications for cobalt and copper are rounded off to 10.

About 300 samples taken from the plough depth were collected from soils cropped with vegetables, fruits, cash crops, field crops and pastures to establish background levels [9].

Safe metal levels in soils have not been established, as these will depend largely on the safe levels in plants, animals and in human foods, which are presently poorly defined. The maxima for recommended metal content in soils (Table 3, column 3), have therefore been based on the total metal concentration in the plough layer. Arsenic, cadmium and nickel maxima have been set at twice the average levels in Ontario soils. This is because of the known toxic effects of arsenic and nickel on plant growth, and in the case of cadmium, because of the greater availability of soil cadmium to plants and due to the low level of tolerance in humans and animals [4,11,12,17,20]. Cobalt, copper, selenium and zinc are deficient for animals in Ontario-grown feed crops; therefore, the recommended maxima have been set at approximately four times the average levels to allow for some build-up in the soil. Chromium, mercury and lead are not required by plants and are also not as readily taken up by crops as other metals; therefore, higher recommended maxima have been set in relation to average levels in spite of the known toxicity of mercury and lead to animals and humans. In addition, chromium has recently been found to be essential for animals and may be deficient in human foods [6]. Molybdenum level of accumulation has been set at four times the average soil level because studies indicate that this metal leaches from soils to a greater degree than most other metals [21].

Once a sludge-amended soil has reached the maximum recommended metal content (Table 3, column 3), no more sludge should be allowed on that particular soil. Therefore, maximum recommended metal loadings in pounds per acre (assuming that 1 acre of soil to the plough depth weighs 2 million pounds) are given in Table 3, column 4.

In addition to setting recommendations for metal loading rates, it is also necessary to determine the acceptability of sewage sludges for agricultural use. The ammonium plus nitrate nitrogen to metals concentration ratios in the sewage sludge provide a relatively simple approach in determining which sludges are suitable for agricultural application. Sewage sludges with ammonium plus nitrate nitrogen to metal ratios

larger than or equal to specified values (Table 3, column 5) are acceptable for agricultural utilization, whereas those with lower ratios are unacceptable and therefore should not be spread on agricultural land.

As an example in the use of Table 3, let us look at selenium. If application of sewage sludge having the minimum nitrogen to selenium ratio of 500 is maintained at the equivalent of 120 lb of ammonium plus nitrate nitrogen per acre per four or five-year period, then 10 applications are required to increase the soil selenium to the maximum recommended level. That is, the 10 applications of sludge would add 2.4 lb/acre of selenium and this would increase the soil selenium content from the average background level of 0.4 ppm to the maximum recommended level of 1.6 ppm. These sludge applications could be made over the next 40 to 50 years. Once a soil has reached the maximum metal content however, no more sludge is recommended on that particular soil and therefore new land should be located to receive the sludge.

Ideally, it would be desirable to make the use of sewage sludge a more permanent feature of food production. However, to make this viable, the implementation of programs to effect metal reduction in sludge will be necessary. Thus, if sewage sludge could be produced having minimum ratios of nitrogen to metals listed in Table 3, column 7 then sludge could be applied to agricultural land over a 200 to 250-year period.

Site Selection

Prior to any application of acceptable sewage sludge to agricultural lands, it will be necessary to examine the physical characteristics of the sites to ensure that they are satisfactory for sewage sludge utilization. Factors such as site location (distance to water courses, water wells, residential developments, etc.), land characteristics (slope of land, permeability of soil etc.) and site management (method and timing of sludge application, etc.) should be considered in order to minimize the pollutional hazards of sewage sludge on surface water courses, water wells, individual human habitations and areas of residential development. Acceptable criteria for all these factors have been formulated and are specified in the proposed guidelines.

SLUDGE UTILIZATION IN ONTARIO

If the recommendations relating to the metal content of sludge are adopted in Ontario, then, based on currently available data, only approximately 14% of the total sludge presently being produced (about 23,900 dry tons/year) would be acceptable for utilization in agricultural production.

The implementation of programs for the reduction of metal concentrations at source or at the treatment plants would be necessary to permit more sludge to be utilized in agricultural production. For example, high levels of certain metals found in municipal sewage (and concentrated in the sludge) may be traced to an industrial source. Through tighter control of municipal sewer use by-laws, industries could be induced to reduce the levels of metals discharged to municipal sewers. This would result in better use of raw materials and reuse of waste products within industry as well as upgrading the quality of Ontario sludges. "Metal reduction at source" would have direct impact on local industry; however, it would appear that this is the most logical approach (where the technology is available) to reducing metal contaminants from municipal sludges. Alternatively, control of the sale of certain household or commercial-use products having high metal content may also be a viable approach. In addition, research work is currently underway to recover heavy metals from sewage sludge. Acid treatment and electroplating or selective precipitation techniques have been successfully used to recover cadmium, copper, nickel and zinc from sludge. However, because of high processing costs, little benefit would be attained from the recovery of trace metals from sludge. Therefore, in terms of improving sludge quality through metal reduction in the sludge, it appears that this is a long-term solution.

Sludges that are unacceptable for agricultural utilization can most suitably be disposed of via landfill or incineration. However, these alternatives are not without inherent problems. For example, all landfills have the potential for contributing to ground and surface water contamination. Incineration is expensive and, with this operation, consideration must be given to the ultimate disposal of the incinerator ash, as well as meeting stringent air quality requirements.

CANADA-ONTARIO AGREEMENT RESEARCH AND PROVINCIAL LOTTERY ENVIRONMENTAL HEALTH RESEARCH FUNDING

Under the Canada-Ontario Agreement [3], joint funding by the Governments of Canada and Ontario was provided for the upgrading of sewage treatment facilities in the Lower Great Lakes Basin. To conduct related research under this agreement, a total of $6 million over a five-year period was provided between 1971-1975 inclusive with an additional $1 million provided for 1976-1977 under a revised Canada-Ontario Agreement.

Sewage sludge treatment and disposal was designated a high priority research area; consequently, a number of projects dealing with sewage sludge utilization on agricultural lands were funded under the Agreement.

Additional studies have been initiated to provide better information on the potential problems associated with the treatment and disposal of sewage sludge. A survey has recently been completed to provide complete documentation on sludge disposal practices in Ontario. Studies have been initiated which include laboratory tests, sludge analyses and field trials to determine the frequency of distribution and the survival rates of parasitic organisms. Another study involves the determination of heavy metal loadings to sewage treatment facilities in residential and in mixed and heavily industrialized municipalities. The object of this latter study is to determine the base level of inputs from residential communities, the magnitude of industrial inputs of heavy metals into sewage systems at selected locations and the viability of effecting controls at source.

The Canada-Ontario Agreement has provided funding to cover research pertaining to sewage sludge utilization up to the end of fiscal year 1977/78. Many of the existing research projects are designed to study the long-term effects of sludge application to agricultural lands; therefore, additional funding must be provided to continue these research activities.

In 1977, the Provincial Lottery Research Fund was set up by the Ontario Government. A total of $5 million over a three-year period was provided to carry out research related to environmental health.

Consequently, some of the research projects initiated under the Canada-Ontario Agreement will be continued with funding provided by the Provincial Lottery.

The intent of the research is to identify methods of determining the acceptability of a particular sludge for land application, to evaluate sludge pretreatment methods prior to land application, and to develop guidelines to effectively control the utilization of sewage sludges as an organic fertilizer without adversely affecting soil, crop, groundwater, and surface waters with nutrients, heavy metals, organic materials or pathogenic organisms.

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APPENDIX

CERTIFICATION PROCEDURES FOR SLUDGE HANDLING

Licensing procedures have been developed so that the following steps will be carried out.

1. The sewage sludge hauler will request application and supporting information forms for a waste management system and organic soil conditioning site or sites from a Regional Office.
2. On notifying the Regional Office that he has bid, Regional personnel will then proceed to inspect the equipment and proposed sites.
3. If the sites prove unsatisfactory, the hauler will be requested to locate additional satisfactory sites. A number of alternate sites must also be provided to handle emergency situations.
4. The Regional Office may also consult other pertinent agencies for their technical inputs on a particular site or system (Air Resources Branch, Ontario Ministry of Agriculture and Food, the local Medical Officer of Health, and local Municipal Authorities).
5. The application and supporting information forms for a satisfactory system and each satisfactory site will then be sent to Head Office along with the Regional Engineer's Recommendation.
6. The Approvals Branch at Head Office will then issue a Certificate of Approval for the system and each site for a maximum period of one year.
7. Distribution of the Certificate of Approval for system and site(s) will proceed as follows:

    a) a copy for the applicant,
    b) a copy for the water pollution control plant,
    c) a copy for the Ministry of Environment at Head Office,
    d) a copy for the Regional Office, from which further distribution may originate.

SLUDGE DISPOSAL PRACTICES AND OPTIONS FOR THE REGION OF WATERLOO

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EFFECT OF THE REGION OF WATERLOO INDUSTRIAL WASTE CONTROL PROGRAM ON THE COMPOSITION OF DIGESTED SLUDGE FROM ITS SEWAGE TREATMENT PLANTS

The Region of Waterloo was formed on January 1, 1973 and came into being under Bill 167 of the Province of Ontario. The three main areas of responsibility assumed by the Region concerning pollution control were:

1. ensuring that the sanitary sewage effluent from all sewers is controlled as to quality and quantity;
2. ensuring that the storm and surface waters within the Region met the requirements set out by the Ministry of the Environment in the Ontario Water Resources Act and our own By-Law 29-73. This function is being administered by the Region, but the Legal Department feels that Bill 167 will eventually have to be amended to specifically make it a Regional responsibility;
3. the control of solid waste disposal according to the Environmental Protection Act and Regional regulations.

The Engineering Department is structured into three divisions namely:

1. roads and traffic;
2. waste management; and
3. water supply.

The Waste Management Division, under the direction of the Environmental Control Engineer, is responsible for the three areas of pollution control mentioned previously. All the sewage treatment plants in the Region are operated by the Ministry of the Environment for the Region.

The Waste Management Division is further broken down into two sections, namely, Sanitary Landfill and the Pollution Control Laboratory. The Pollution Control Laboratory administers By-Law 29-73, the Industrial Waste Control By-Law.

By-Law 29-73 which was passed in April, 1973 sets out clearly under what conditions and at what contaminant levels industrial wastes can be accepted into the sanitary and storm systems within the Region. This by-law has been updated to ensure that the latest revisions as recommended by the joint Ministry of the Environment/Municipal Engineers Association Liaison Committee have been included.

The laboratory is divided into three basic sections: administrative, field services, and testing lab. The administrative section consists of a supervisor and assistant supervisor reporting to the Environmental Control Engineer. The field services section consists of a field services technologist and three sampling technicians. This section obtains information from industries, does appropriate sampling and returns the same to the laboratory for analyses, syntheses and report writing. The testing laboratory section is staffed by a certified engineering technologist and four laboratory technicians, one of whom is a graduate microbiologist and another a graduate chemist.

The level of technical qualification in the Pollution Control Laboratory is high and is in keeping with the complexity of the projects initiated. The laboratory also has a competent clerk-stenographer who keeps a complete file system of large quantities of data which must be readily accessible.

The laboratory in both field and chemical sections is equipped with the most up-to-date and sophisticated equipment available. The field section has automatic sampling equipment and flow measuring devices which together are capable of obtaining the most accurate effluent samples possible. The chemical laboratory is fully equipped with all the necessary wet chemical apparatus and also has an extensive instrumentation section which includes an atomic absorption spectrophotometer, an infrared spectrophotometer and a gas chromatograph.

The main method by which information is gathered is through industrial waste surveys. The field section surveys the industry,

documenting all the waste effluent and materials generated by the plant. These liquids and solids are carefully analysed, flows are measured and an environmental impact assessment made on the disposal practices.

From this information, the Region informs the industry where they stand with respect to any violations of By-Law 29-73 and advises where process changes might be necessary to eliminate potential problems. We are not consulting engineers and therefore we do not try to design process changes or systems for industries. However, we do assist industry wherever possible by making suggestions on how to improve their effluent to meet our standards and recommend the engagement of consultants when warranted. This program has been a success and all the metal fabricating and plating industries are now meeting our heavy metal standards. We have one tanning industry in Kitchener which is completely changing plant lay-out and process in order to meet our chromium standards. Chromium is one heavy metal in the present Kitchener sewage sludge which does not meet Phase I Sludge Guidelines for land disposal. It is hoped that the above-mentioned process change in the chrome tanning industry will bring the Kitchener sludge within Phase I land disposal criteria. Although the 1976 data show zinc to be a problem at the Kitchener plant, we are confident that 1977 data will show it to be within the guidelines due to our continued work with the plating industries.

In October of 1971, while employed by the City of Kitchener, Mr. Robert MacDonald, the Assistant Pollution Control Supervisor, performed some interesting work on the investigation of metallic wastes entering the Kitchener Water Pollution Control Plant. From his extensive studies the following observations were made:

(i) The Kitchener Water Pollution Control Plant received weights of metals on an annual basis with their ultimate disposition shown in Table 1.

(ii) This plant removed approximately 78% of the chromium, approximately 75% of the zinc, approximately 100% of the copper and practically none of the nickel.

TABLE 1. KITCHENER WATER POLLUTION CONTROL PLANT (1971)

	lbs/yr				
	CHROMIUM Cr	NICKEL Ni	COPPER Cu	ZINC Zn	TOTAL MEANS
Received at Plant	36,402	16,220	5,088	26,510	84,220
To Digesters	28,489	Approx. 0	5,088	19,783	53,380
Discharged to River	7,913	16,220	0	6,727	30,880

(iii) The significant area for metal removal is the secondary section of the plant. The primary section does remove some chromium and zinc.

(iv) A substantial amount of metallic waste reached the Grand River and caused an average of 0.14 mg/L total metals (calculated) concentration below the Kitchener outfall to the Grand River. This concentration does not include any background concentrations which might already be in the river and does not include iron or aluminum.

(v) It appeared that 53,380 lb of chromium, copper and zinc ultimately accumulated in the digested sludge at the Kitchener plant in 1971. This metal was subsequently spread on farmland.

(vi) This metal has a monetary value approaching $300,000 per year. Metal conservation is now being practiced more and more by industry as our industrial waste program progresses.

The Kitchener plant has been expanded since these tests were made and the figures do not represent the present situation. In 1975 tests on metallic concentrations in the Kitchener Water Pollution Control Plant digesters showed dramatic reductions in all metals except iron. Iron has probably increased because of the introduction of iron salts by the Ministry of the Environment as a chemical for phosphorus removal.

Due to the highly variable, non-homogenous nature of sewage sludge, and the difficulty of its sampling, care must be taken in making

too many conclusions. However, it does appear that the Kitchener sludge would not give us difficulty in meeting Phase I guidelines with respect to NH_3-N/Cr and NH_3-N/Zn ratios. With process improvements being installed at the tanning company, chromium also should meet the guidelines.

All metals in the sludge from Kitchener will be re-examined thoroughly during 1978 to find out where to focus our next metal control program. The expanded 27 mgd plant which went on-stream in October, 1977 will undoubtedly show that the sludge characteristics have again changed. The effluent BOD and SS from the Kitchener plant are both now less than 10 ppm. The former Kitchener Water Pollution Control Plant had a design capacity of 11.5 mgd primary and 13.5 mgd in the secondary. It had been running over design capacity for several years.

Many similar industrial waste control changes as that of the tanning plant have taken place throughout the Region due to the industrial waste control program. It can be hopefully concluded that all the sewage sludge generated within the Region of Waterloo will within six months meet the Phase I land disposal guidelines with respect to ammonia-nitrogen heavy metal ratios.

Most metals entering the sanitary sewer systems in the Region are limited by by-law to a maximum of 5 mg/L sludge disposal guidelines; the by-law can always be amended by Council to make it more restrictive. However, industry's ability to meet tighter constraints has to be considered. Up to the present time the Region of Waterloo has had extremely good cooperation from industry. There are 600 industries in the Region with 236 having significant amounts of industrial waste to monitor and control. There are 39 with metallic wastes needing monitoring twice per month. This persistent monitoring of the industries with metallic wastes is required to ensure that proper controls are being maintained.

The Pollution Control Laboratory staff inventory industrial discharges and prepare reports for distribution to the concerned industry which contain recommendations for amendments to discharge quality if necessary. To date the laboratory has 250 contacts on file for which approximately 200 reports of various types have been written. In addition, reports have been written in regard to sanitary waste and

leachate production at landfill sites, as well as water quality reports on potential potable water sources. Water well rejuvenation effluent control procedures have been instituted at the Waste Management Division's recommendation. The Region of Waterloo presently relies totally on groundwater wells for its supply of water.

The laboratory staff is constantly working with industry to improve wastewater quality. Testing of waste samples is carried out continuously by following a scheduled program. Approximately $1,000,000 per year has been spent by private industry since the Region was formed in installing in-plant pollution control equipment. Presently, there are only two industries not able to meet out standards with respect to toxic wastes. Both these companies have major programs underway which will, hopefully, meet our requirements by the spring of 1978.

Other areas where the laboratory staff are actively involved are:

1. water conservation within industry,
2. encouraging the area municipalities in the reduction of infiltration into and the removal of extraneous clean water from their sanitary sewer systems,
3. providing a 24-hour emergency spill control program for oils and toxic wastes,
4. water quality monitoring for the Waste Management Division's Sanitary Landfill Section,
5. methane gas monitoring for the Waste Management Division's Sanitary Landfill Section,
6. a road testing and road materials testing program for the Roadways Division,
7. a water quality testing program for the Water Supply Division,
8. material testing for the Purchasing Department,
9. a high quality uniform Regional Pollution Control Service available to all seven area municipalities (before Regional Government, Kitchener was the only area municipality with this service),

10. a volume sewer surcharge refunding service to the area municipalities,
11. a strength sewer surcharge charging service to the area municipalities,
12. reports on sewage treatment plant operations,
13. assisting the Ministry of the Environment in solving sewage treatment operating problems.

CURRENT SLUDGE PRODUCTION AND DISPOSAL PRACTICES IN THE REGION OF WATERLOO AND THE POSSIBLE IMPACT OF THE PROPOSED LAND DISPOSAL GUIDELINES

In a book entitled, "Sewage Disposal," written by Kinnicut, Winslow and Pratt in 1911, the following statement was made: "The problem of the ultimate disposal of sludge presents greater difficulties than any other question connected with sewage treatment". This statement applies as much today as 67 years ago even though many improvements have been made in sludge disposal understanding and in the equipment available.

Today the public is better informed and its concern about the protection of the environment has created new problems in the disposal of sludge. In addition, we now have to contend with the increasing cost of energy and the presence of such things as heavy metals, trace elements, non-biodegradable organic compounds and plastics. These constraints add many restrictions to the processing, handling and disposal of sludge.

The Region of Waterloo has 10 sewage treatment facilities, all presently operated by the Ministry of the Environment. Table 2 gives the NH_3-N to metal ratios in the sludge from the four largest plants. The sludge from the Kitchener plant is the only sludge not presently meeting the proposed guidelines for land disposal. The current acreage used for sludge disposal from these four plants is 10,007. To meet the guidelines of Phase I land sludge disposal as presently proposed, the Region of Waterloo would need 17,300 acres. This could double the cost because of the increased haul distance required, as this increased acreage will have to be found in areas of the Region much more distant from the sewage plants. This could raise the present average cost of $38.87/dry ton for land disposal of sludge to close to $80.00/dry ton.

TABLE 2. REGIONAL MUNICIPALITY OF WATERLOO 1976 DATA FOR SLUDGE DISPOSAL
(Four Largest Plants) RATIOS (NH_3-Nitrogen to Metals)

	KITCHENER	WATERLOO	CAMBRIDGE (GALT)	CAMBRIDGE (PRESTON)	MINIMUM RATIO ALLOWED UNDER GUIDELINES
Cr	2.04*	19	27	124	6
Zn	2.50*	20	17	24	4
Cu	21	26	27	48	10
Ni	4,240	283	409	3,100	40
Pb	1,178	94	82	78	15
Cd	1,710	773	500	1,000	50
Mn	66	142	129	124	N/A
Mg	2.25	2.6	3.1	4.4	N/A
Co	2,120	1,666	3,000	3,444	50
Hg	-----	154,545	-----	108,771	1,500
Mo	-----	2,035	-----	3,444	250
Vol. Sludge (million gal/year)	19.60	13.5	6.2	5.7	
NH_3-N (mg/L)	1,060	850	900	620	
Acreage Required	8,700	4,800	2,300	1,500	
Acreage Currently In use	5,000	3,200	935	872	

* Indicates ratio is too low (i.e. sludge unacceptable)

These costs merit the consideration of dewatering plus incineration. (See Table 3.) When one considers incineration with waste heat recovery and co-incineration with shredded municipal refuse accompanied by heat recovery, costs could become even less than land disposal.

Heavy truck traffic is associated with sludge haulage onto farmland. As the urban municipalities expand, these trucks have to travel more and more through or near recently developed residential areas. These trucks have created noise problems, especially as they travel to and from the Kitchener Water Pollution Control Plant. Many residents have complained and at one time a study was made into alternate routes for this truck traffic. It turned out that there were no other routes available and the affected residents have to live with this problem. Other methods of sludge disposal such as incineration could practically eliminate this truck noise problem, but at a cost higher than present land disposal. The sludge could also be piped to a storage area beyond the urban confines of the plants. From these remote storage areas, it could either be trucked onto farmland for land disposal or processed in some other manner.

You will see by Table 2 that 46.1 million gallons of anaerobically digested sludge with an average total solids of 3.2% were spread on land in the Region of Waterloo in 1976. This volume will increase as the Region grows and more sophisticated types of sewage treatment are implemented. This increased production of sewage sludge will require larger acreages for land disposal. Eventually it will be impossible to find more land and other methods of sludge disposal will have to be implemented. It appears that land disposal, disregarding any toxic constituents, has a limited life but because of its economy, it will be practiced as long as possible. Land disposal is convenient and less capital intensive than other methods, especially at the smaller plants located in the midst of rural townships. It appears that the region of Waterloo should examine all options for sludge disposal both from individual plants and from a combination of plants.

Table 4 shows the current per unit cost of sludge disposal on land from the different sewage treatment plants in the Waterloo Region.

TABLE 3. ESTIMATED TYPICAL COSTS OF SLUDGE DISPOSAL PROCESSES PER DRY TON, 1974*

METHOD	COST PER DRY TON (U.S. DOLLARS, 1974)
DEWATERING	
Vacuum filter	31
Centrifuge	26
Sand beds	30
INCINERATION	
(Total cost including dewatering)	50-85
LAND TRANSPORT	
Tank Truck (5% solids)	3 per mile
Dump Truck (30% solids)	0.65 per mile
STORAGE	
Lagoon (5% solids)	14
Stockpile (30% solids)	2.30
DISPOSAL ON LAND	
Landfill (5% solids)	3
Landfill (30% solids)	3
Land spreading (5% solids)	20
Land spreading (30% solids)	10

* Summarized from "Decision-Maker's Guide in Solid Waste Management", prepared by Office of Solid Waste Management Programs, U.S. Environmental Protection Agency, 1976.

TABLE 4. CURRENT SLUDGE DISPOSAL COSTS (1977) (Land Application)

PLANT	COST/1,000 GALLONS	COST/CU YD LIQUID
Cambridge (Galt)	6.50	1.09
Elmira	6.87	1.15
Wellesley	7.20	1.21
St. Jacobs	6.20	1.04
Cambridge (Hespeler)	5.90	0.99
Waterloo	6.00	1.00
Baden	7.44	1.25
Cambridge (Preston)	6.00	1.00
Kitchener*	6.85	1.15

* Unit liquid cost of $1.15/cu yd; hauled disposal cost from lagoon of $2.45/cu yd; hauled this is equivalent to $0.85/cu yd liquid.

Table 5 shows the annual cost for sludge disposal on land for the Region of Waterloo for all the individual plants and in total. It is noted that it cost $295,171.00 to land dispose 7,602 dry tons of sludge or $38.87 per dry ton in 1976. This involved the hauling and spreading of 46.1 million gallons of average 3.29% total solids sludge over 10,500 acres of farmland.

SLUDGE DISPOSAL IN CONJUNCTION WITH SOLID WASTE DISPOSAL

The Region of Waterloo in conjunction with the Ministry of the Environment has just completed a "systems study" into a method of converting combustible solid waste into energy while recovering the ferrous waste. One of the main conclusions of this study is that energy in the form of "Refuse Derived Fuel" (RDF), constitutes a recoverable resource from municipal waste which could earn revenues of sufficient magnitude to justify the construction of such a plant at an initial 600 tons per day capacity. If we proceed along this basis it would conceivably be possible to use this RDF mixed with 35% solid sewage sludge cake to fire furnaces which in turn could supply steam and electrical energy. The wastefulness of incinerating sludge or garbage, at least in large plants, without making full use of the heat generated is apparent. The Region of Waterloo situation would have to be studied to determine the economies and advantages of moving to such a method of sludge disposal as opposed to the present land disposal method.

Incinerators to burn sewage sludge cake operated in conventional burning and in-pyrolysis modes both with and without refuse burning but with energy recovery will see more and more use in the future. Several plants in design today will operate in this fashion. At the Central Contra Costa Sanitary District's new 30 mgd plant in California, USA, studies of many energy and resource recovery schemes led to the recommendation that the combustion or pyrolysis of sewage sludge and Refuse Derived Fuel be adopted. Full-scale tests performed there indicate that pyrolysis of the mixed solid waste and sewage sludge produced an off-gas with enough heat energy to power the entire treatment works. The ash which will remain from such an operation could pose a problem in disposal because of the heavy metals which might be present.

TABLE 5. SLUDGE DATA (1976) FROM VARIOUS SEWAGE PLANTS IN THE REGIONAL MUNICIPALITY OF WATERLOO

PLANT	VOLUME (million gal./yr) FOR LAND DISPOSAL 1976	PERCENTAGE TOTAL SOLIDS	DRY TONS/ ANNUM	LAND DISPOSAL COST/ANNUM	COST/DRY TON
Kitchener	19.6	4.0	3,920	$ 138,976	$ 35.45
Waterloo	13.5	2.7	1,823	73,879	40.53
Cambridge (Galt)	6.2	3.0	930	42,649	45.85
Cambridge (Preston)	5.7	2.8	798	29,258	36.66
Cambridge (Hespeler)	0.9	2.4	108	9,254	85.68
Elmira	----	---	-----	---------	-----
St. Jacobs	0	---	-----	---------	-----
Wellesley	0.2	1.5	15	1,155	77.00
Baden	----	---	-----	---------	-----
TOTALS	46.1		7,594	$ 295,171	

Average Cost/Dry Ton = $\frac{\$\ 295,171.00}{7,594}$ = $ 38.87

Average Percentage Total Solids of Sludge = 3.29

Either recovery of these metals or their chemical fixation before landfill disposal would solve this problem.

With the increasing cost of energy and its decreasing availability in the forms we are accustomed to, organic sewage sludges which have been either anaerobically or aerobically digested and dewatered to a high degree will be used to fire heat recovery incinerators or pyrolysis units to recover energy. Undigested sludge followed by dewatering could also be used as organic fuel leading to energy recovery.

The addition of RDF (Refuse Derived Fuel) to the dewatered sludge could provide the needed scale requirement for an incinerator with heat recovery to make the project economically attractive. This could solve both the sludge disposal and solid waste disposal problems at the same time while recovering energy. Disposal of organic type wastes by landfill will be discouraged more and more in the future. It is these wastes which lead to most severe landfill problems such as contamination of groundwater, surface water and migration of methane gas. Sanitary landfill sites are becoming more and more difficult to establish because of public reaction against them. Present sites must be preserved and made to last as long as possible. The production of RDF would help solve this problem as well as provide an alternative energy source.

A static pile method of composting sewage sludge has been recently developed. Windsor has one of these in operation. The regularity of sludge production necessitates a continuous market for either its sale or its free distribution and the need for storage when markets are inactive. This is particularly significant where the compost is used for agricultural or other beneficial purposes. There must be enough reliability and durability of the market that expensive stand-by or alternative means for handling the steady production of sludge are avoided. Advocates see disposal as no problem and predict a great demand once users are informed of its benefits. Of all the known and proven processes and methods of preparing sludge for disposal, composting may be one of the best to meet the criteria of energy, economy, resource recovery, and minimal environment abuse. Heavy metals would have to be reduced to a minimum, however, again preferably at the source. Composting of sludge in general has had a poor experience record because of uncertain markets.

SUMMARY

The Region of Waterloo will keep rigid controls on industries to ensure that their sanitary wastes have a heavy metal content low enough that all the sewage sludge within the Region can meet the sludge guidelines for land disposal. Even with the sludge meeting the guidelines, substantially more land will be required for disposal, resulting in rising costs.

As land disposal may not continue to be economical, a thorough study should be made on sludge disposal within the Region of Waterloo. This study should examine all the alternative methods of sludge disposal other than direct haul onto land. These other methods should be analysed not only on the basis of economics, but also on their various environmental impacts and then compared with our present and future land disposal practices under the new guidelines.

Possible alternatives to direct land disposal of sludge include processing for use as fertilizer or soil conditioner, disposal in landfilling sites, or worked out gravel pit areas, and all modes of incineration, both with and without energy recovery and both with and without co-incineration with combustible municipal solid waste.

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SLUDGE THICKENING, CONDITIONING AND DEWATERING FUNDAMENTALS

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INTRODUCTION

Until recently, sludge processing, handling and disposal operations have either been ignored, glossed over, shrouded in mystery or dealt with by using the "black box" approach.

How often have we seen a design drawing, or are even guilty ourselves of having drawn an arrow from a digester or other treatment process and labelled it "TO DISPOSAL"? We are thus, not only ignoring up to 60% of the total waste treatment costs but contributing to the treatment plan operators' headaches as well. Solids handling and disposal can neither be ignored nor tacked on to a treatment system as an afterthought. It must be considered as an integral part of any complete waste treatment system. Some papers in this seminar will address this topic by examining the various unit operations for sludge processing and disposal (Figure 1). An attempt will also be made to share past and current experiences and reacquaint you with the principles underlying the various unit operations and processes in sludge handling and disposal.

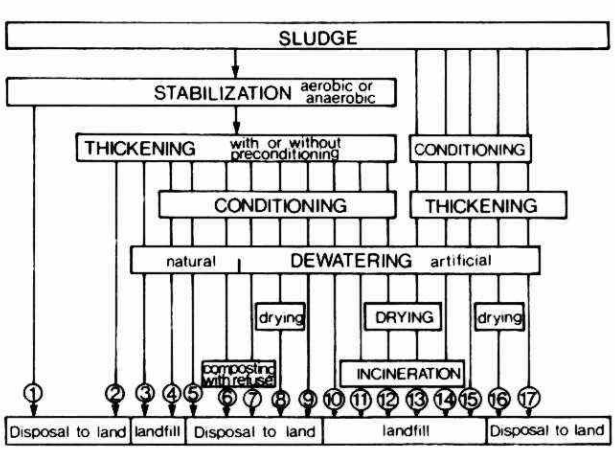


FIGURE 1. UNIT OPERATIONS FOR SLUDGE PROCESSING AND DISPOSAL

The objective of this paper is to examine unit processes involving the unit operations of sludge thickening, conditioning and dewatering. More specifically, we will explore the fundamentals underlying each of the unit processes to be discussed during this Seminar, and identify dependent and independent variables associated with each unit process.

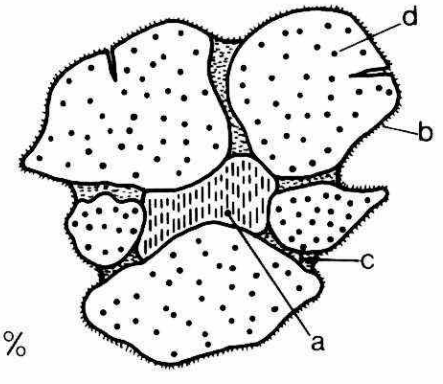
An understanding of the fundamentals is the first step in putting us into a better position to design, select, operate and troubleshoot sludge thickening, conditioning and dewatering operations.

SLUDGE PARTICLE CHARACTERISTICS

To explore the application as well as limits of thickening and dewatering operations, we must examine the nature of the sludge itself. A high moisture content is characteristic of sludges. We all agree that the smaller the sludge volume, the more economic the whole disposal operation. Hence, our major objective consists of water removal or solids concentration.

The sludge moisture content is a function of both particle size and its organic content. The smaller the particles, the higher the moisture content. The higher the organic fraction, the higher the moisture content.

Basically, two types of water are present in sludge. Free water and bound water. Figure 2 is a water distribution schematic for a digested sludge flow. Up to 70% of the water present is not attached to any solids and is called free water. This can be removed by thickening.



-water type-
a - free 70%
b - floc 20%
c - capillary 2%
d - intracellular (particle) 8%

FIGURE 2. WATER DISTRIBUTION SCHEMATIC FOR A SLUDGE FLOC

The bound water fraction of 22% is made up of floc and capillary water. These waters stay with the floc particles and can only be removed by sludge particles deformation as would occur in a mechanical dewatering process. The remaining 8% is adsorption and intracellular fluid (particle water). This fluid is chemically bound to the individual particles and can only be removed by drying and combustion processes. The advantage of sludge moisture content reduction is illustrated in Figure 3. Here, for example 1000 m^3 of a sludge with an original moisture content of 95% will be reduced to 50% of its original volume (500 m^3) by bringing the moisture content to 90%.

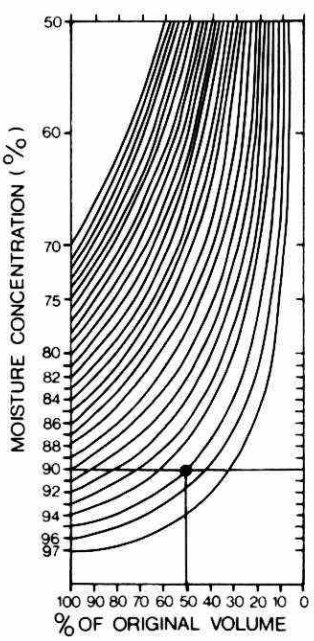


FIGURE 3. MOISTURE CONTENT-VOLUME REDUCTION RELATIONSHIP

The relationship between water volume reduction and the various unit operations of thickening, dewatering and drying is summarized in Figure 4. It illustrates that in removing all of the free water by thickening, the original volume of 1000 litres with a moisture content of 95% has been reduced to a volume of 333 litres at a moisture content of 85%. Similarly, dewatering processes can remove the floc and capillary water resulting in a final volume of 125 litres with 60% moisture content. Figure 5 is similar to Figure 4 but identifies the various available unit process options. As well, incineration has been added.

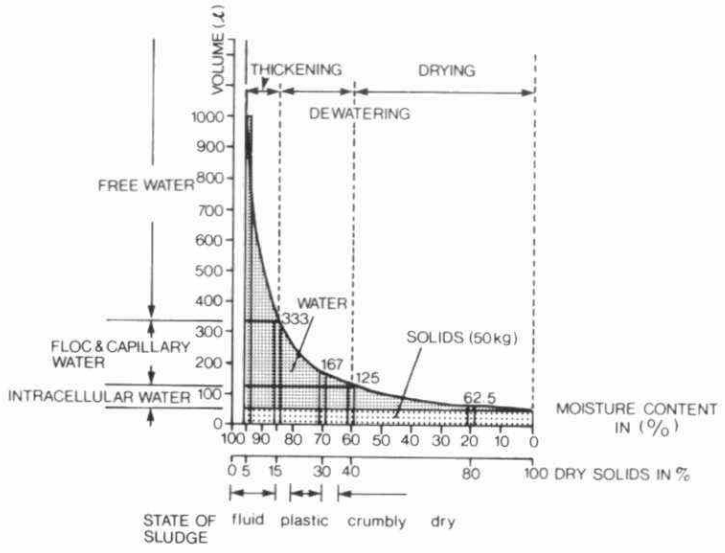


FIGURE 4. WATER VOLUME REDUCTION VS UNIT OPERATION RELATIONSHIP [1]

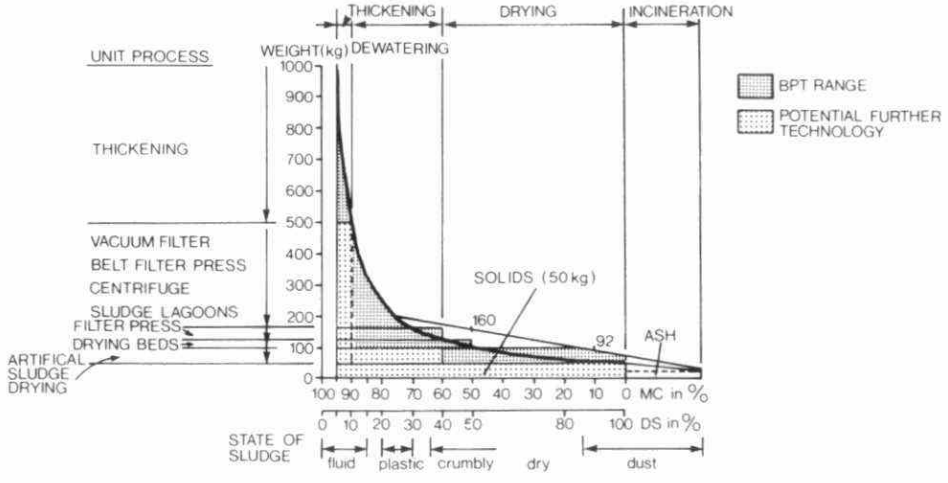


FIGURE 5. BEST PRACTICAL TECHNOLOGY FOR SLUDGE VOLUME REDUCTION BY WATER REMOVAL AND INCINERATION [1]

It was stated earlier that sludge particle size governs, to a large extent, the amount of water present. In order to obtain an appreciation of the particle sizes under consideration, Figure 6 compares the particle size distribution of an unflocculated primary digested sludge to some common materials. As much as 75% of the total particles fall in the 5-100 micron range and compare to silt and fine sand.

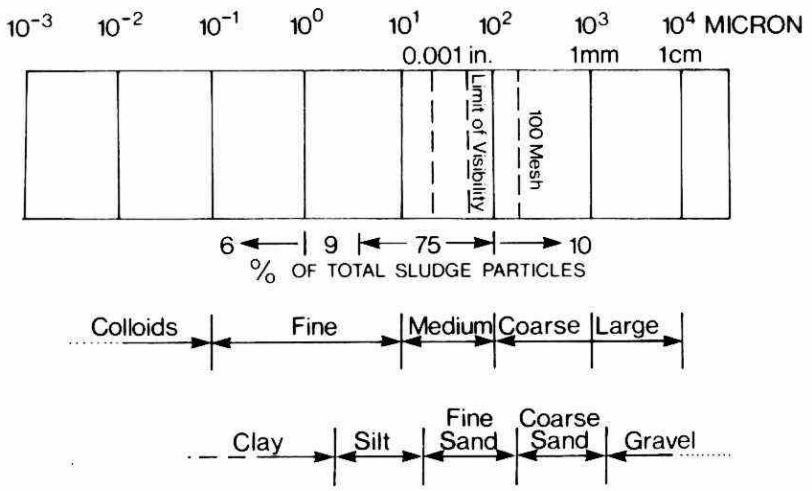


FIGURE 6. PARTICLE SIZE COMMON MATERIALS [2]

A further consideration in sludge handling is the physical state of fluidity of the sludge. Figures 4 and 5 correlate the sludge fluidity with respective unit operations and dry solids concentration. Beyond solids concentrations of 20%, the sludge no longer is pumpable.

Using flow properties (rheology) is one way of classifying fluids. Figure 7 is a rheogram for various fluids. It shows that fluids may range from plastic to dilatant, and have a functional relationship between shear stress and shear rate. For a Newtonian fluid, this relationship is expressed as:

$$\tau \propto \frac{du}{dy} = \mu \frac{du}{dy} \qquad (1)$$

where: τ = shear stress ($ML^{-1}T^{-2}$)

μ = dynamic viscosity ($ML^{-1}T^{-1}$)

$\frac{du}{dy}$ = shear rate (T^{-1})

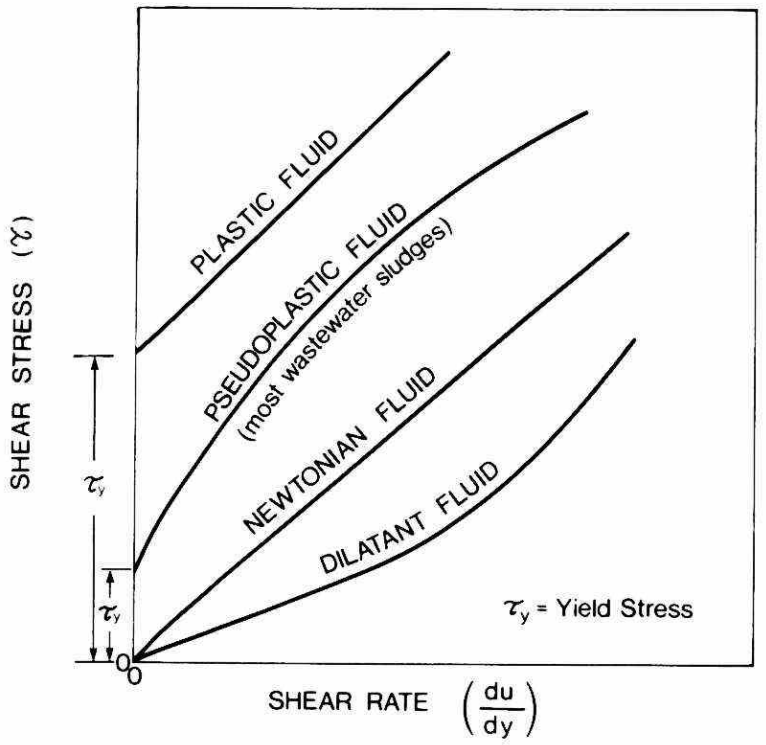


FIGURE 7. RHEOGRAM FOR VARIOUS FLUIDS

On the other hand, a plastic fluid is one which requires an initial shear stress (τy) before it can be displaced. τy is defined as the yield stress. Mathematically, this is expressed as:

$$\tau = \tau_y + \eta \frac{du}{dy} \qquad (2)$$

where: η = the coefficient of rigidity or plastic viscosity ($ML^{-1}T^{-1}$).

Most wastewater sludges fall somewhere between these two extremes and are identified to behave as pseudo-plastic fluids. But that is not all; with sludges the rheologic properties also change with time. This is known as thixotropy and is illustrated in Figure 8 by the typical hysteresis loop.

Because viscosity is one of the dependent variables, sludge temperature and solids concentration play a most important role in sludge rheology. (Viscosity decreases with increasing temperature and decreasing solids concentration.)

Attempts have been made to categorize sludges in accordance with the degree of difficulty of liquid-solid separation. In general, sludges

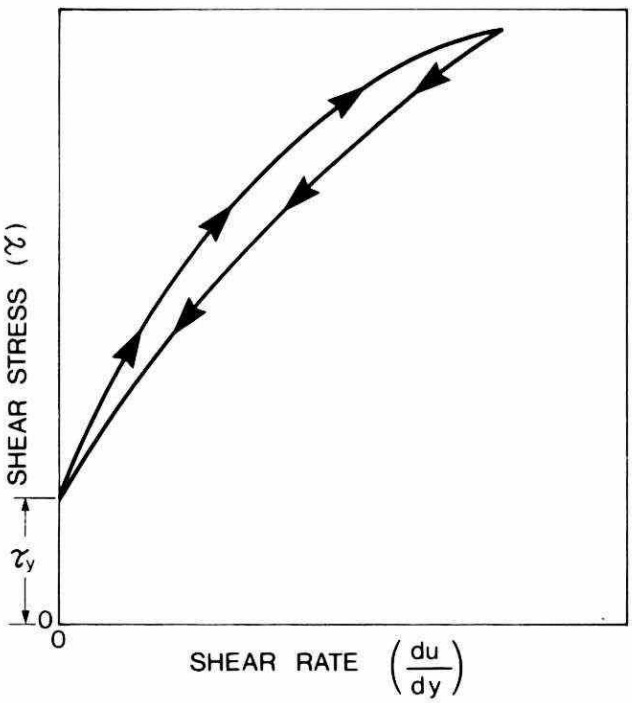


FIGURE 8. SLUDGE RHEOGRAM SHOWING THIXOTROPIC BEHAVIOUR

can be divided into three groups as shown in Table 1, ranging from sludges which are easy to dewater to sludges that are very difficult to dewater. To the first group of sludges belong those which have a low organic content. Here, without conditioning, thickening alone can reduce the moisture content to 75%. Pressure filtration will produce a filter cake with a 30 to 40% moisture content. Industrial sludges such as those from the metal finishing industry, certain chemical industries, as well as poorly stabilized municipal sludges, are all examples of sludges which are difficult to dewater. Here, thickening without conditioning may reduce the moisture content to only 97% which, with mechanical dewatering

TABLE 1. SLUDGE CHARACTERIZATION ACCORDING TO WATER REMOVAL LIMITS [1]

SLUDGE CATEGORY (DEGREE OF DIFFICULTY OF WATER REMOVAL)	THICKENING LIMITS % MC (NO CONDITIONING)	DEWATERING LIMITS % MC	
		VACUUM FILTRATION BELT FILTER PRESS CENTRIFUGE	PRESSURE FILTRATION (E.G. FILTER PRESS)
EASY	75	-	40 - 30
MEDIUM	90 - 85	80 - 70	65 - 60
DIFFICULT	99 - 97	85 - 80	75 - 70

may ultimately be reduced to 70%. Most municipal sludges fall somewhere between these two extremes. Following digestion, the moisture content of municipal sludges is approximately 95%. This can be further modified by thickening (without conditioning) to as low as 85%. Mechanical dewatering processes can reduce the moisture content down to a value of 60%.

The various types and quantities of water associated with a sludge floc were identified earlier. We also illustrated the unit operation associated with removing these waters. We should, at this time, see how much energy may have to be expended in order to remove these waters. It is no great revelation to find that the more intimate the waterbonding, the higher the energy input required to break this bond. Table 2 illustrates orders of magnitude in energy requirement for the removal of waters from 1 m^3 of sludge using the various unit operations. The energy requirements range from 10^{-3} kwh/m^3 for thickening, where we remove the free water, to 10^3 kwh/m^3 for thermal drying where the chemically bound water is removed.

TABLE 2. ENERGY REQUIREMENTS FOR WATER REMOVAL FROM SLUDGE [1]

UNIT OPERATION	ENERGY REQUIREMENT KWH (GROSS) / M^3 SLUDGE
THICKENING	$\sim 10^{-3} - 10^{-2}$
DEWATERING	$\sim 10^{0} - 10^{1}$ (EXCLUDING CONDITIONING)
THERMAL DRYING	$\sim 10^{3}$

Only the sludge treatment unit operations involving water volume reduction or solids concentration, thickening, conditioning and dewatering will be discussed here. Some of the available sludge reduction and disposal operations will be presented by other speakers at this Seminar.

SLUDGE THICKENING

Before discussing sludge thickening in some detail, we should define it. It is generally accepted that the reduction in water content to 85%, while arbitrary, represents a reasonable division between sludge thickening and dewatering processes.

The advantages of thickening may be self-evident and can be summarized as follows:

1. reduction in digester volume due to higher influent solids concentration;
2. reduction in external heat requirements for digestion;
3. reduction in drying area for digested sludges;
4. reduction in length of sludge pumping cycle (reduced pumping costs);
5. reduction in capital and operating costs for sludge dewatering, handling and disposal processes;
6. reduction in energy costs for sludge incineration.

Clearly, sludge thickening, while much neglected, offers the potential for a much more efficient treatment plant design. Where would you use a thickening process? There are numerous possibilities; however, the following four applications are the most frequently used:

1. Pre-thickening - for raw sludge, excess sludge and mixed sludges. This leads to reduced digester volume requirements.
2. Pre-thickening - with or without conditioning as a preliminary step to artificial sludge dewatering processes.
3. Post-thickening - for digested sludges as a preliminary step to ultimate disposal or for thin sludges, digester supernatants to reduce the organic loading on the treatment plant or for organic load equalization.
4. Post-thickening - to handle separated sludge waters from artificial sludge dewatering processes, (e.g. filtrate, decant, centrate, etc.).

Sludge thickening may be accomplished by any one of the unit processes of settling, flotation, elutriation or centrifugation which are summarized in Table 3. The frequency of usage of these unit processes and their relative success are also identified.

THICKENING BY SETTLING

Settling and thickening are interrelated by the fact that in settling we are concerned with producing a clear overflow, whereas in

TABLE 3. OCCURRENCE OF THICKENING METHODS IN SLUDGE TREATMENT [2]

METHOD		TYPE SLUDGE	OTHER PERTINENT CONSIDERATIONS	FREQUENCY OF USAGE AND RELATIVE SUCCESS
GRAVITY		RAW PRIMARY	SEPARATE WAS * THICKENING	INCREASING-EXCELLENT RESULTS
		DIGESTED PRIMARY	SEPARATE WAS THICKENING	INFREQUENT NOW; BUT FEASIBLE
		RAW PRIMARY AND WAS	RECIRCULATION OF WAS TO PRIMARIES	DECREASING - USUALLY POOR
		RAW PRIMARY AND WAS	DIRECT MIXED SLUDGE THICKENING	SOME NEW INSTALLATIONS - MARGINAL RESULTS
		WAS	SEPARATE PRIMARY SLUDGE THICKENING	ESSENTIALLY NEVER USED - POOR RESULTS
	ELUTRIATION	DIGESTED PRIMARY AND WAS MIXTURE	SECONDARY DIGESTERS OR ELUTRIATION	MANY PLANTS BUILT - REQUIRES FLOCCULANTS
DISSOLVED AIR FLOTATION		RAW PRIMARY AND WAS	DIRECT MIXED SLUDGE THICKENING	RARELY USED
		WAS	SEPARATE GRAVITY THICKENING OF PRIMARY	INCREASING - GOOD RESULTS
CENTRIFUGATION	SOLID BOWL CONVEYOR TYPE	WAS	SEPARATE GRAVITY THICKENING OF PRIMARY	SOME LIMITED USE - SOLID CAPTURE PROBLEM
	DISC TYPE	WAS	SEPARATE GRAVITY THICKENING OF PRIMARY	SOME LIMITED USE - DATA NOW BEING ACCUMULATED

* waste activated sludge

thickening, our major concern is the production of a concentrated underflow. Let us examine what happens when we take a cylinder filled with sludge which is intimately mixed and then allowed to settle. The progression through four distinct zones of settling is shown in Figure 9. Immediately after mixing is discontinued at time zero, and for a very short time, sludge particles having overcome acting inertial and viscous forces settle due to gravitational forces by free or discrete settling. Here, the particles maintain their identity and do not change in size, shape or density. Meanwhile, a little further down in the column, a solids-liquid interface has developed where particles coalesce, resulting in a change in specific gravity and settling rate. This is the zone of flocculant or hindered settling. The suspension still remains at uniform concentration and the magnitude of the settling velocity is a function of the initial solids concentration. Concurrently, a zone of transition is formed when the settling velocity decreases due to the increasing concentration of solids. When the rising layer of settled solids intersect

the interface (zone settling), a compression zone occurs. Solids are supported mechanically by the solids below. Generally speaking, primary sedimentation is a good example of flocculant settling, whereas the settling of concentrated (>500 mg/L) biological suspensions falls into the category of zone settling.

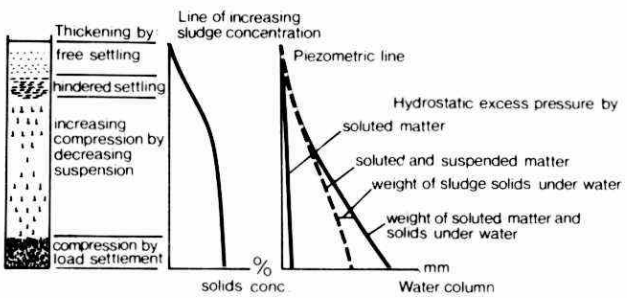


FIGURE 9. ZONES OF GRAVITY THICKENING [4]

For a continuous gravity thickener, the solids concentration profile is illustrated in Figure 10. The interface between the clear zone and the feed zone is defined as the sludge blanket. It can be seen from Figure 10 that by increasing the underflow, the sludge blanket can be lowered. This has the effect of lowering solids residence time, lowering the underflow solids concentration but increasing the reserve

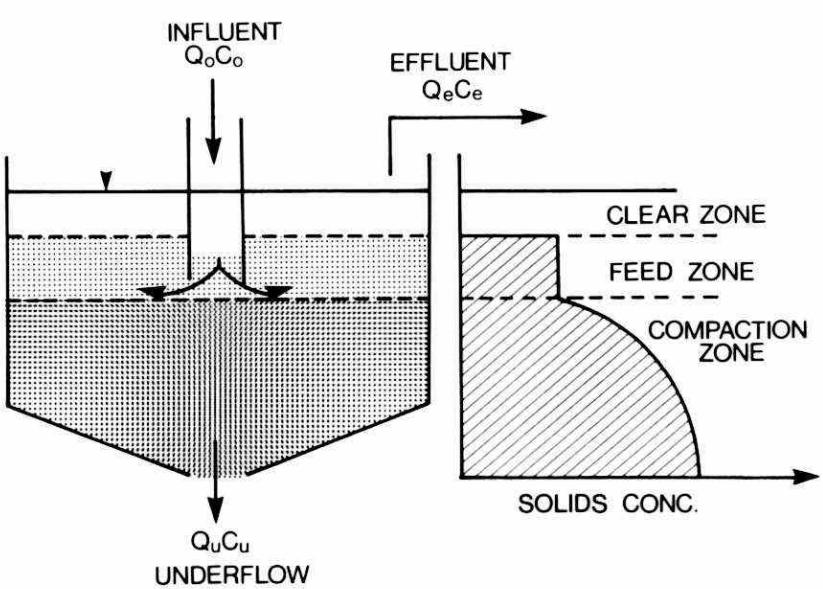


FIGURE 10. CONTINUOUS FLOW THICKENER [3]

capacity for handling additional solids. On the other hand, maintaining a high sludge blanket will not only result in a higher solids underflow concentration, but increase the solids retention time as well. This could lead to formation and release of gas due to anaerobiasis with resultant flotation of solids and their carry-over into the effluent.

Practical experience has borne out laboratory observations that gentle agitation of the sludge will assist the thickening action by opening channels for dislodgement of bubbles, the release of water and assisting particle agglomeration. Hence, most continuous thickeners are equipped with thickening rods (Figure 11).

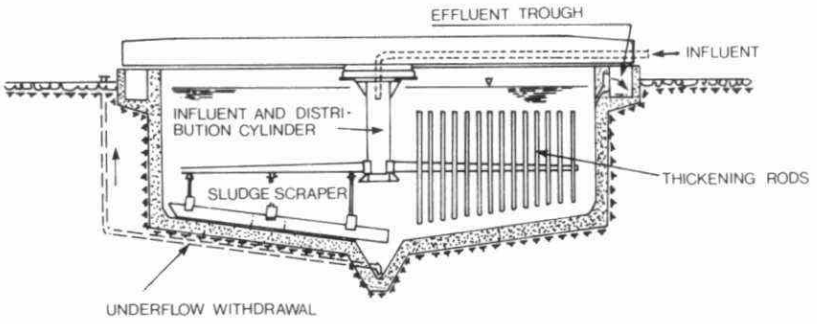


FIGURE 11. CONTINUOUS THICKENER WITH STIRRING AND SCRAPING MECHANISMS [1]

The Sludge Volume Index (SVI) can be used as an indicator of the rheologic state of the sludge, but is not necessarily related to yield stress or viscosity. That rheological properties influence gravity thickening was indirectly illustrated by Kalbskopf [4] where he correlates the SVI to solids concentration of gravity thickened activated sludge (Figure 12). A Sludge Volume Index of 200 corresponds to a solids concentration of 2.5%, whereas an SVI of 50 resulted in a solids concentration of 9%. Additional evidence showing the influence of sludge rheological properties on solids concentrations achieved by gravity thickening of various sludge types is summarized in Table 4.

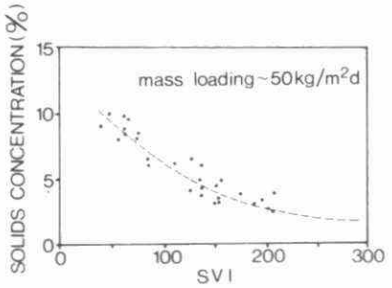


FIGURE 12. GRAVITY THICKENING OF ACTIVATED SLUDGE [4]

TABLE 4. SOLIDS CONCENTRATION BY GRAVITY THICKENING [4]

SLUDGE TYPE	SOLIDS CONCENTRATION AFTER GRAVITY SETTLING (%)
MIXED PRIMARY AND INDUSTRIAL (COAL)	10 - 30
PRIMARY:	
VOLATILE SOLIDS >65%	5 - 7
VOLATILE SOLIDS <65%	7 - 12
PRIMARY AND ACTIVATED:	
SVI >100	4 - 6
SVI <100	6 - 11
EXTENDED AERATION	3 - 5
PRIMARY & TRICKLING FILTER	7 - 11
PRIMARY DIGESTED	8 - 14
ACTIVATED DIGESTED	6 - 9
HEAT-TREATED ACTIVATED	10 - 15

Clearly then, aside from the raking action and the rheological properties of the sludge, the major variable which can and is controlled in the operation of gravity thickeners is sludge blanket depth. For the design of gravity thickeners we rely on batch settling tests conducted in the laboratory. Suffice it to note at this time that the thickener surface area can be calculated [5]:

$$A = Q_o \, C_o / G_L \tag{3}$$

where: A = thickener surface area (L^2)

Q_o = influent flow rate (L^3T^{-1})

C_o = influent solids concentration (ML^{-3})

G_L = limiting solids flux ($ML^{-2}T^{-1}$)

and the underflow rate of the thickened sludge can be determined by conducting a mass balance around the thickener as shown in Figure 10.

$$Q_o \, C_o = Q_e \, C_e + Q_u \, C_u \tag{4}$$

since

$$Q_e = Q_o - Q_u$$

$$Q_o \, C_o = Q_u \, C_u + C_e \, (Q_o - Q_u) \tag{5}$$

where: Q_e = effluent flow rate (L^3T^{-1})

Q_u = underflow rate (L^3T^{-1})

C_e = supernatant solids concentration (ML^{-3})

C_u = underflow solids concentration (ML^{-3})

A successful design methodology is illustrated by Campbell et al [6].

Thickening by Flotation

Flotation can be thought of as upside-down clarification and is generally employed where we wish to produce a sludge with a higher solids concentration than we can obtain by gravity settling. As with settling, flotation is a unit operation involving separation of solid particles from a liquid phase.

In order to overcome the normally acting gravitational force on a sludge particle, fine air bubbles introduced into the system adhere and/or are trapped in the floc particle structure. The resulting increase in buoyancy leads to an upward movement of the particles into the thickening zone.

The contact between gas bubble and floc particle is physical as well as the result of intermolecular attraction exerted at the interface between the three phases (solid, liquid, gas). As shown in Figure 13 (a), the interaction of forces is due to the interfacial tensions between the phases. The angle α between the three phases at the point of contact is defined as the angle of contact. The force diagram in Figure 13 (b) shows that interfacial tension equilibrium between the three phases exists when:

$$\sigma_{GS} = \sigma_{SL} + \sigma_{GL} \cos \alpha \qquad (6)$$

where: σ_{GS} = interfacial tension between gas and solid phases (MT^{-2})

σ_{SL} = interfacial tension between solid and liquid phases (MT^{-2})

σ_{GL} = interfacial tension between gas and liquid phases (MT^{-2})

If σ_{GS} is greater than σ_{SL} then the contact angle α is greater than zero and the gas bubble can adhere to the solid. The tendency for the gas bubble to adhere to the solid increases with the size of the contact angle. Thus, for effective flotation, we must either promote flocculation (i.e. increase the floc size) to enhance bubble contact

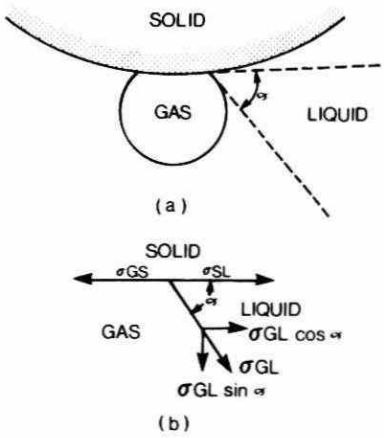


FIGURE 13. INTERFACIAL TENSIONS EXISTING IN A THREE-PHASE SYSTEM [7]

and capture, or we must change the surface properties of the sludge floc. Various groups of chemicals are commercially available to aid flotation by altering the surface properties of the phases involved [7].

Various patented systems for introducing air bubbles into the liquid exist. Liquid may either be injected into the air or air into the liquid. Dissolved rather than dispersed air flotation is more commonly used. Gas bubbles of 70 to 90 microns in diameter are precipitated in the flotation unit from a super saturated solution by the sudden reduction in pressure (e.g. from 276-414 kN/m^2 to atmospheric).

As the floc particle rises, it finally encounters the sludge blanket which can be anywhere from 20 to 60 cm thick. This is where sludge thickening occurs. The buoyant force of the sludge/air bubble complex forces the surface of the sludge blanket above the water level, thereby inducing drainage of water from the sludge particles. A typical dissolved air flotation unit schematic is shown in Figure 14.

It is of interest to list the primary variables involved in dissolved air flotation. They are:

1. feed solids concentration,
2. solids and hydraulic loading rate,
3. air to solids ratio,
4. detention time,
5. recycle ratio,
6. pressure,
7. sludge characteristics,
8. use of chemical aids.

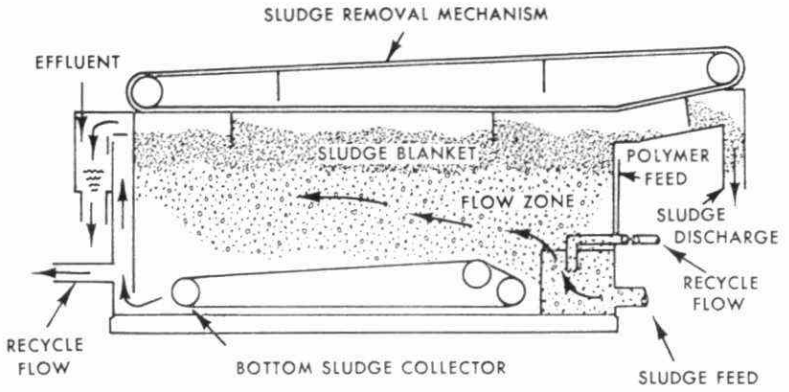


FIGURE 14. FLOW SCHEMATIC OF A FLOTATION UNIT

Experience has shown that sludge characteristics affect the performance of flotation units to a lesser degree than gravity thickeners. Waste activated sludge can normally be thickened to a higher solids concentration using flotation rather than gravity thickening. As well, by combining primary and activated sludge, a higher float concentration can be obtained. Bulking sludges will result in a poorer float solids yield.

Detention time in the flotation zone is not critical, provided the particle rise rate is adequate and that the horizontal velocity is sufficiently low that scouring of the sludge blanket does not occur.

The advantages and disadvantages of using dissolved air flotation as opposed to gravity thickening of activated sludge can be summarized as follows:

Advantages	Disadvantages
- reliability	- higher operating costs (power and flotation aids)
- thicker sludge	- greater operator skill level required
- higher solids loading	
- better solids capture (~97%)	
- sludge remains aerobic	

Experience has shown that flotation operations cannot be designed on the basis of mathematical formulations. Preliminary design data must be generated from lab tests and final design criteria from pilot scale work.

A design procedure for dissolved air flotation is presented by Campbell et al [6].

Thickening by Elutriation

Elutriation is a sludge washing process with the objective of changing the physical and chemical sludge characteristics. It not only eliminates fines and colloidal matter but also reduces sludge alkalinity. While elimination of fine and colloidal particles enhances sludge thickening, reductions in alkalinity will reduce inorganic chemical conditioning requirements for subsequent sludge dewatering operations.

Elutriation may be conducted in one or two stages in batch or continuous mode. Figure 15 and 16 illustrate single and two-stage elutriation process steps. The elutriation tanks are similar in construction to thickeners, the only difference being that a large volume of water is added to the sludge at the tank inlet. The concentration of sludge obtainable is similar to gravity thickening (5.5 to 6.0 percent); however, the supernatant from the elutriator contains a high concentration of fines and colloidal matter. This is generally recirculated to the head of the plant and re-adsorbed by the flocculated sludge.

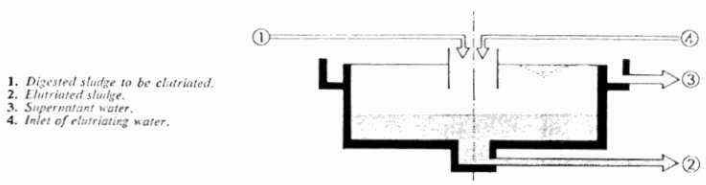


FIGURE 15. SINGLE-STAGE ELUTRIATION [8]

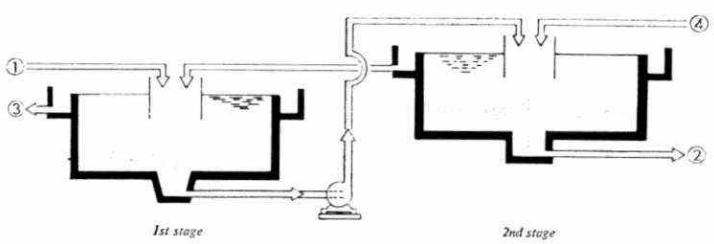


FIGURE 16. TWO-STAGE ELUTRIATION [8]

Since the major objective of elutriation is sludge conditioning, more specific details concerning this process will be discussed later in this paper under the heading of Sludge Conditioning.

Thickening by Centrifugation

To date, sludge thickening by centrifugation has found limited application. Thus, few data are available. Some evaluations of disc, solid-bowl and basket centrifuges have been conducted on waste activated sludge, achieving solids concentrations of 6, 7 and 9%, respectively.

At this time, the status of centrifugal sludge thickening can be summed up as follows:

1. Chemicals are required to prevent floc break-up due to high shear.
2. Conditioning is required to achieve 90% solids capture.
3. A low SVI is a pre-requisite for achieving 90% solids capture.
4. Operational costs are high.
5. Basket centrifuges may have a role to play in small waste treatment installations.
6. Centrifugal thickening will be less competitive if gravity or flotation thickening without chemicals can be achieved.
7. Space limitations or unusual sludge characteristics may make this process economically attractive.

SLUDGE CONDITIONING

Up to now, we have dealt with removing water by thickening processes. We have stated earlier that even after thickening we still have a water content of up to 85%. While we have removed a substantial amount of the free water (Figure 2) we must remove some of the bound water before the sludge can be trucked or shovelled (20% DS). In order to assist in the removal of bound water, energy will have to be expended to modify the cohesive forces and destabilize the solids. Table 5 summarizes some of the conditioning methods in use and their function as related to sludge thickening and more specifically, to sludge dewatering.

Three sludge conditioning alternatives of either organic or inorganic chemical addition, elutriation, or heat treatment may be practiced. Experience has shown that the method of sludge conditioning selected has not only a significant effect on the sludge thickening or

TABLE 5. CONDITIONING METHODS AND PURPOSES [2]

CONDITIONING METHOD	UNIT PROCESS	FUNCTION
POLYMER ADDITION	THICKENING	IMPROVE LOADING RATE, DEGREE OF CONCENTRATION AND SOLIDS CAPTURE.
POLYMER ADDITION	DEWATERING	IMPROVE PRODUCTION RATE, CAKE SOLIDS CONTENT AND SOLIDS CAPTURE.
INORGANIC CHEMICAL ADDITION	DEWATERING	IMPROVE PRODUCTION RATE, CAKE SOLIDS CONTENT AND SOLIDS CAPTURE.
ELUTRIATION	DEWATERING	DECREASE ACIDIC CHEMICAL CONDITIONER DEMAND AND INCREASE DEGREE OF CONCENTRATION.
HEAT TREATMENT	DEWATERING	ELIMINATE OR DECREASE CHEMICAL USE, IMPROVE PRODUCTION RATE, CAKE SOLIDS CONTENT AND STABILIZATION. SOME CONVERSION MAY ALSO OCCUR.
ASH ADDITION	DEWATERING	PROVIDE IMPROVED CAKE RELEASE FROM BELT TYPE VACUUM FILTERS AND FACILITATE FILTER PRESSING. IT CAN ALSO RESULT IN HIGHER FILTER YIELDS AND REDUCED CHEMICAL REQUIREMENTS.

dewatering operation, but on the liquid treatment portion of the plant as well. This aspect is extremely well illustrated in the U.S. Environmental Protection Agency's Sludge Treatment and Disposal Design Manual [2]. In their hypothetical example, recirculation increased the solids load to the aeration system by 65%.

One method of assessing the effectiveness of sludge conditioning is the determination of the specific resistance of a sludge. It is a measure of sludge filterability and varies with pressure, area, solids concentration and liquid viscosity. Specific resistance is defined as the pressure required to produce a unit rate of flow through a cake having a unit weight of dry solids per unit area when the viscosity of the liquid is unity.

Specific resistance, having units of m/kg is determined from laboratory filtration experiments using the Buchner Funnel test.

Figure 17 illustrates the effect of chemical conditioning on specific resistance for some sludge types. Clearly, without chemical addition, mechanical dewatering would hardly be feasible.

Chemical Conditioning

Generally, chemical conditioning methods involve the use of organic or inorganic flocculants to promote the formation of a porous, free-draining cake structure. In this way, the flocculants improve

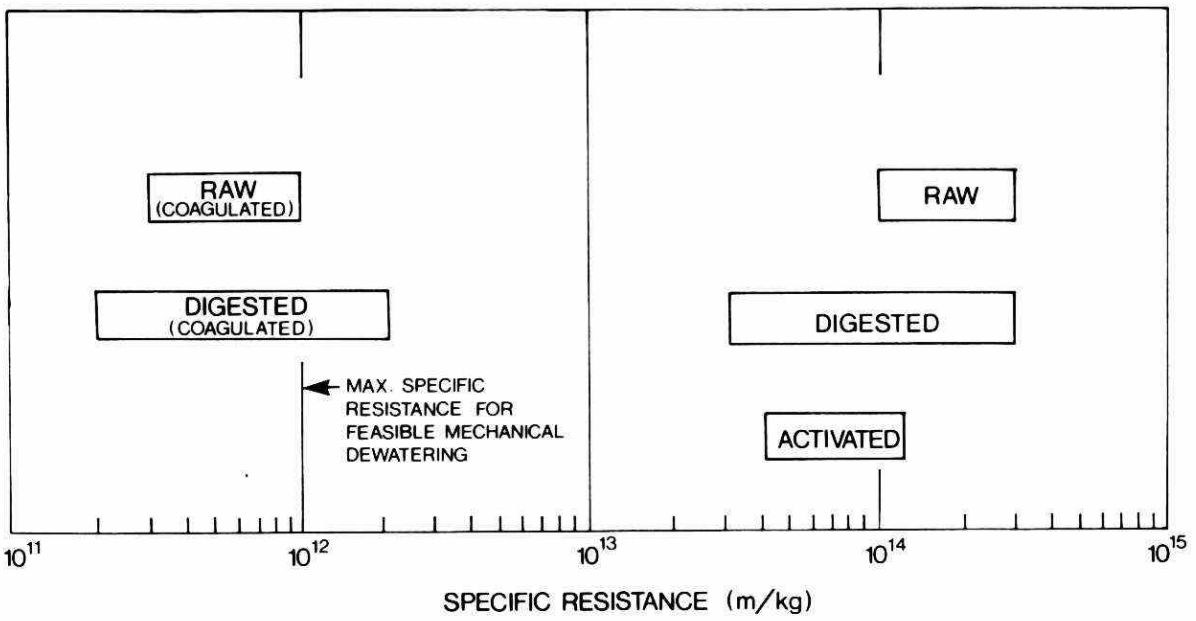


FIGURE 17. THE EFFECT OF CHEMICAL CONDITIONING ON SPECIFIC RESISTANCE FOR VARIOUS SLUDGE TYPES

sludge dewaterability, alter sludge blanket properties and improve solids capture. More specifically, chemical conditioning as applied to thickening processes causes the flocculants to promote more rapid phase separation, higher solids concentration and a greater degree of capture; whereas in dewatering, chemical conditioning will enhance the degree of solids capture by destabilization and agglomeration of fine particles. This then promotes the formation of a cake which later becomes the true filter media in the dewatering process.

The prime characteristic of sludge particles is their large surface area. This provides not only highly chemically active surface sites but allows for water to be held by adsorption. Sludge particles are generally negatively charged. This charge is acquired by preferential adsorption of ions from the solution. The end result of this is that swarms of ions of the opposite charge are attracted and arrange themselves in two layers around the particle. Strongly attracted ions form what is defined as the compact double layer while the less strongly attracted ions form the diffuse double layer (Figure 18). The magnitude of the charge on the particle derived from the compact double layer is called zeta potential and represents the repelling force of the particle

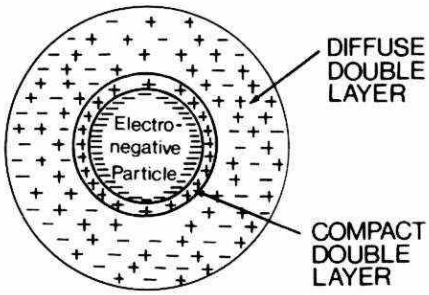


FIGURE 18. SLUDGE PARTICLE CHARGES [9]

(Figure 19). The interparticle force of mass attraction also acting on the particles in suspension is called the Van der Waals force.

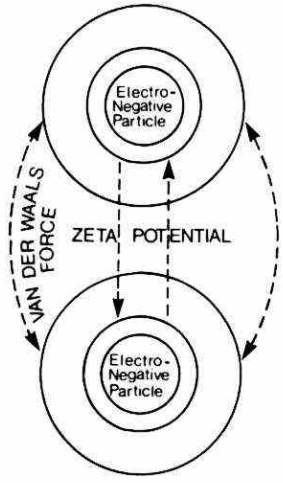


FIGURE 19. ZETA POTENTIAL [9]

One objective of sludge conditioning then is to effect a reduction of the zeta potential, which will cause water to be released. As well, the particles will come closer together to the point where the Van der Waals forces start to become effective. This causes particle aggregation.

As stated earlier, sludge particles generally carry a negative charge but depending on the net charge of the suspension, they may be flocculated by either cationic or anionic polyelectrolytes (Figure 20). Polymers used in flocculation are long-chain, water soluble organic molecules of high molecular weight and carry a large charge density when dissolved. Polyelectrolytes flocculate by neutralizing the surface charges on the sludge particles, by desorption of bound water and through bridging.

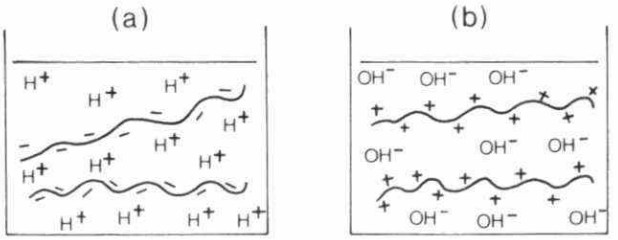


FIGURE 20. POLYMERS a-ANIONIC b-CATIONIC [9]

Figure 21 shows a variety of mechanisms thought to be involved in the flocculation mechanism. The binding of sludge particles may be effected by forces of mass attraction or by chemical bonding mechanisms. The binding mechanism in successful sludge conditioning may be visualized as involving the capture of sludge fines on the stems and branches of the polymers followed by the formation of a tight aggregate of sludge particles cross linked by polymer fibers. While the close proximity of the particles effects release of held water, the fibrous structure gives strength to resist attraction from forces applied during subsequent dewatering operations. It is thus the increased pore space between the particles and the release of held water effected by the conditioning agents which improve the dewatering characteristics of a sludge.

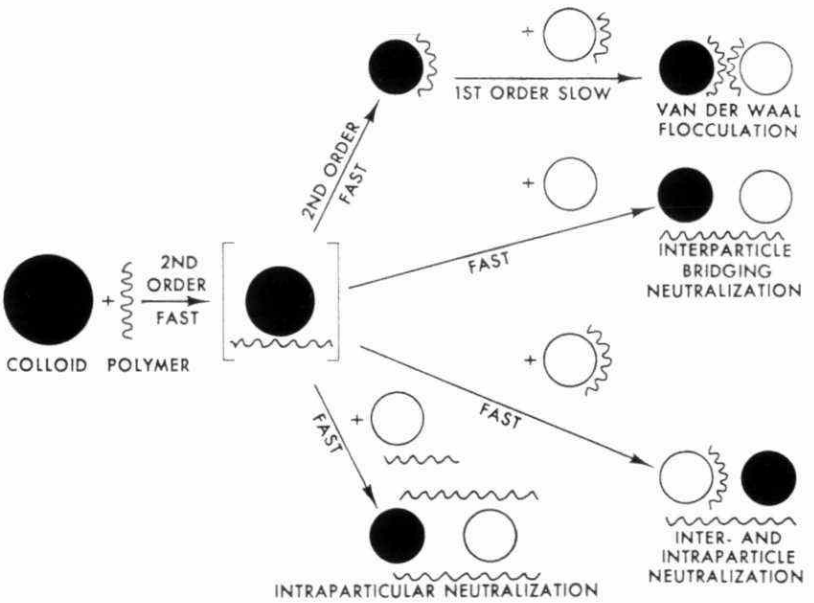


FIGURE 21. MECHANISM OF POLYMER FLOCCULATION [10]

The most frequently used chemical for sludge conditioning is $FeCl_3$ alone or in combination with CaO. Experience has shown that, while by no means universally applicable, $FeCl_3$ and CaO are chemicals successfully used for the conditioning of raw and digested sludges, while the use of $FeCl_3$ alone has been successful for waste activated sludge. The chemical dosage requirement for $FeCl_3$, for example, can be calculated on the basis of the alkalinity, volatile matter and dry solids concentration of the sludge. The amount of CaO to be added is generally between 150 to 250% of the $FeCl_3$ dosage for an unelutriated sludge.

Aside from economic considerations, overconditioning can have an equally detrimental effect as underconditioning. It is thus highly recommended that specific resistance measurements be conducted in order to determine the chemical requirements for sludge conditioning not only for design but process control purposes as well.

Elutriation for Conditioning

As defined earlier, elutriation is a sludge washing process with the objective of changing physical and chemical sludge characteristics.

Sludge conditioning of digested sludges in preparation for mechanical dewatering processes usually exerts a high coagulant demand due to the presence of alkalinity or bicarbonates. The alkalinity of a digested sludge can easily be 100 times that of fresh sludge. Hence, if the alkalinity can be reduced by a washing (elutriation) process, then in many instances, the cost of elutriation can more than offset the cost of chemicals [12]. The reduction in conditioning chemicals requirement is also reflected in increased heat values of the sludge cake.

As noted earlier, elutriation can be a batch or continuous operation. Batch operation permits close control and requires a minimum of equipment, whereas a continuous process offers more flexibility, is relatively easy to operate but requires more equipment.

The design variables involved in elutriation are [9]:

1. Nature of the sludge:
   - digested primary, easy to elutriate,

- combined digested primary and activated, elutriation is more difficult,
- digested activated, elutriation is most difficult.

2. % volatiles:
   - low volatiles = higher initial density = heavier elutriated sludge.
3. % dry solids (DS):
   - the higher the initial DS the higher the elutriated solids content.
4. Method of elutriation:
   - countercurrent method requires least amount of wash water for desired alkalinity level.
5. Elutriation ratio:
   - the higher the required elutriation ratio, the larger the tank must be for settling.
6. Operating schedule:
   - continuous operation = adequate for several hours of filtration,
   - batch, single stage = storage = adequate for filter run.

A correlation between decrease in sludge alkalinity and chemical requirements ($FeCl_3$) was established by Genter [13] as:

$$p_c = \left[\frac{1.08 \times 10^{-4} Ap}{100-p}\right] + \left[1.6\,\frac{pv}{pf}\right] \qquad (7)$$

where: A = alkalinity of sludge (mg/L as $CaCO_3$)

p_c = % of chemical
p = % of moisture
pv = % of volatile matter
pf = % of fixed solids

} in sludge on dry basis

As a consequence of higher levels of secondary treatment, larger amounts of fine particles result. Unless flocculants are used, the elutriate will thus be extremely dirty and impose a considerable recirculation load on the treatment systems.

Thermal Conditioning

Sludge conditioning by heat treatment refers to the pressure cooking of sludges in such a manner that little oxidation of sludge occurs. It is distinct from wet air oxidation which generally involves higher temperatures and pressures with air injection to promote a major degree of sludge oxidation.

The objective of heat treatment is to break the bond between the bound water and the floc particles. As well, during heat treatment (150 - 260°C, 1240 to 1450 kN/m^2, 20 - 30 min. detention time) sludge particles are solubilized and hydrolyzed, thus releasing cell protoplasm as well as some of the intracellular water. This enhances dewaterability. It is not surprising to find that the filtrate from a thermally conditioned sludge is extremely strong (BOD_5 = 15,000 mg/L, COD = 80,000 mg/L, organic carbon = 6,000 mg/L). Treatment of the filtrate in the aeration tank is possible. However, recent experiments [11] have indicated that pre-treatment of the filtrate by anaerobic digestion is considerably more attractive.

Earlier, we discussed the term "specific resistance" and indicated that it is used as a measure of sludge dewaterability. Figure 22 shows the effect of heat treatment reaction temperature on specific resistance for sludges of differing volatile solids content. An increase in reaction temperature or a decrease in volatile solids content will

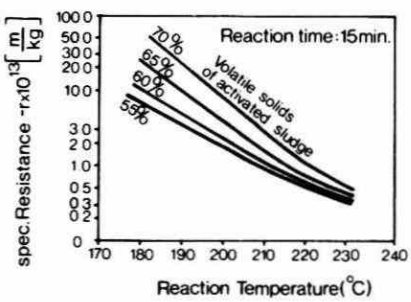


FIGURE 22. INFLUENCE OF REACTION TEMPERATURE ON SPECIFIC RESISTANCE [11]

reduce the specific resistance. As well, the effect of heat treatment reaction time on specific resistance for sludges at different process operating temperatures is shown in Figure 23. An increase in reaction time at constant temperature for a specific sludge will decrease the specific resistance.

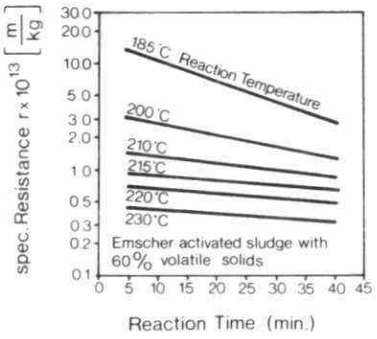


FIGURE 23. REACTION TIME - SPECIFIC RESISTANCE [11]

The advantages and disadvantages of thermal conditioning can be summarized as:

Advantages	Disadvantages
- process is effective for all organic sludges	- external heat required
- sludge is disinfected	- higher operator skill level required
- sludge thickens and dewaters readily	- odours

Other Conditioning Methods

A number of other methods for sludge conditioning have been tried either at pilot or full scale with varying degrees of success. Examples are freeze-thawing, electro-osmosis, solvent extraction and the addition of inert materials such as ashes, sawdust and paper fibres.

SLUDGE DEWATERING

In dewatering processes, we now must overcome the intermolecular forces which bind the water to the solids. We are after the floc and capillary water which represents 22% of the water in the sludge and can only be removed by sludge particle deformation. Selection of the appropriate dewatering process is not only a function of many process variables, but considerations of pretreatment and ultimate disposal. Table 6 illustrates this relationship between dewatering processes and other sludge treatment processes. For example, if sludge incineration was the only ultimate disposal alternative, then it would make little sense to

TABLE 6. THE RELATIONSHIP OF DEWATERING TO OTHER SLUDGE TREATMENT PROCESSES FOR TYPICAL MUNICIPAL SLUDGES [2].

METHOD	PRETREATMENT NORMALLY PROVIDED		NORMAL USE OF DEWATERED CAKE			
	THICKENING	CONDITIONING	LAND-FILL	LAND-SPREAD	HEAT DRYING	INCINERATION
ROTARY VACUUM FILTER	YES	YES	YES	YES	YES	YES
FILTER PRESS	YES	YES	YES	VARIABLE	NOT USUALLY	YES
HORIZONTAL BELT FILTER	YES	YES	YES	YES	YES	YES
CENTRIFUGE (SOLID BOWL)	YES	YES	YES	YES	YES	YES
CENTRIFUGE (BASKET)	VARIABLE	VARIABLE	NO	YES	NO	NO
DRYING BEDS	VARIABLE	NOT USUALLY	YES	YES	NO	NO
LAGOONS	NO	NO	YES	YES	NO	NO

dewater sludge by lagooning. In general, the various sludge dewatering processes can be put into two groups:

1. artificial dewatering,
2. natural dewatering.

Processes belonging to the artificial dewatering category consist of: vacuum filtration, pressure filtration, filter presses and centrifugation. Natural dewatering processes are lagooning, drying beds and freeze-thaw. By use of mechanical dewatering processes, the sludge water content can be reduced from approximately 85% to 60%. Some typical examples of mechanical dewatering process performance are summarized in Table 7. It is of interest to note that pressure filtration (filter

TABLE 7. PERFORMANCE DATA FOR VARIOUS MECHANICAL DEWATERING PROCESSES [1]

PROCESSES FOR ARTIFICIAL, MECHANICAL SLUDGE DEWATERING	MEDIAN PERFORMANCE	MEDIAN MOISTURE CONTENT	MEDIAN ENERGY REQUIREMENT
	KG DS/M^2·H KG DS/M·H M^3/H	%	KWH/M^3 SLUDGE THROUGHPUT
NEGATIVE FILTRATION (VACUUM)	~10-30 KG DS/M^2·H	~ 70 - 80	~ 6
POSITIVE FILTRATION (PRESSURE)	~ 4 - 8 KG DS/M^2·H	~ 50 - 70	~ 2
BELT FILTER PRESS	~100-200 KG DS/M·H	~ 75 - 80	~ 1
CENTRIFUGE	~5-20 M^3/H (~200-1500 KG DS/H)	~ 75 - 80	~ 2

press) can produce a sludge with an exceptionally low moisture content ranging from 50 - 70% for an energy requirement of 2 kwh/m^3 sludge throughput as compared to a moisture content range of 70 - 80% at an energy expenditure of 6 kwh/m^3 sludge throughput for vacuum filtration.

Dewatering by Filtration

Filtration is a unit operation involving the separation of solids from liquid using a filter medium which permits the passage of fluid but not particles. As noted earlier, in the case of sludge dewatering, it is the sludge cake which becomes the true filter medium. Thus, rate of cake formation, porosity, structure and water release characteristics are the dominant factors in cake filtration. Figure 24 shows an idealized, incompressible cake with constant voidage. Here the particles do not deform, and porosity and thus resistance to filtration remain constant even though a pressure gradient exists. Thus, there is no significant increase in resistance to filtration as a function of time. However, sludge cakes are nearly always compressible, hence with particle deformation, voidage decreases and resistance to filtration increases. This is shown in Figure 25.

Filtration may be carried out by gravity, under negative pressure, positive pressure or by gravitational force. However, for concentrated, heterogeneous mixtures of solids and liquid, unit operations involving only the last three force applications apply.

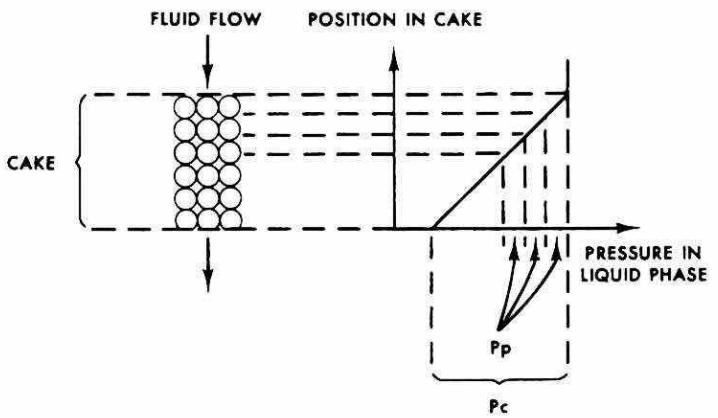


FIGURE 24. FLUID FLOW THROUGH AN INCOMPRESSIBLE SLUDGE CAKE [14]

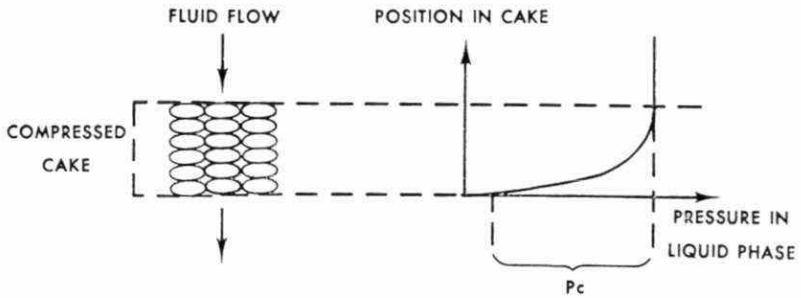


FIGURE 25. FLUID FLOW THROUGH A COMPRESSIBLE SLUDGE CAKE [14]

Negative pressure

Vaccum filtration. Vacuum filtration is carried out on a slowly rotating drum filter partially submerged in a tank containing the sludge to be filtered. A vacuum is applied to the drainage compartments in the drum interior, causing a sludge mat to form on the filter surface as the drum turns. Figure 26 shows a vacuum filter schematic with the appropriate operating zones encountered in one drum revolution. In the first zone, known as the pick-up or form zone, with the internal compartments linked to the vacuum source, liquid is drawn through the filter cloth leaving solids to form a cake. As the drum rotates, the formed cake emerges from the sludge and thus enters the dewatering or drying zone. Here drainage of the cake continues under continued application of a vacuum. The last zone is known as the discharge zone.

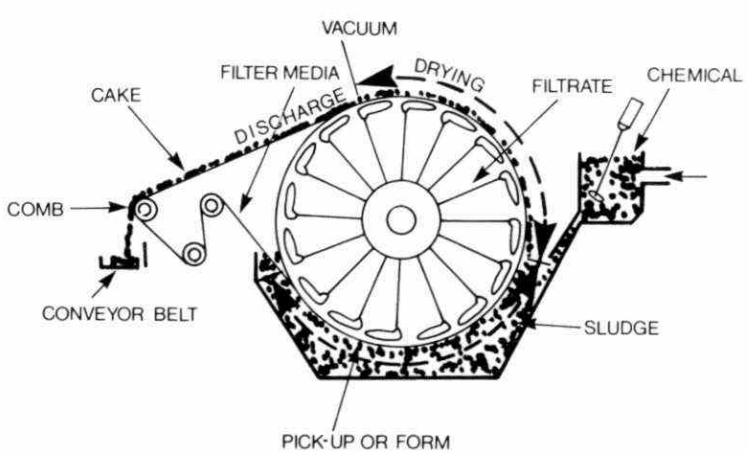


FIGURE 26. CAKE PROCESSING PHASES - ROTARY VACUUM FILTER [2]

The important variables involved in vacuum filtration can be divided into machine and operational variables as follows:

Machine Variables	Operational Variables
- vacuum pressure	- type and condition of sludge
- drum submergence	- conditioning of sludge
- drum speed	- sludge characteristics:
- degree of sludge agitation	- initial solids concentration
- filter medium	- nature of solids
	- chemical composition
	- sludge compressibility
	- sludge age
	- temperature
	- sludge and filtrate viscosity

Some of the operational variables such as viscosity and sludge temperature are clearly outside the control of the plant operator. However, some of the machine variables such as vacuum pressure, drum submergence and drum speed can be manipulated.

In order to see what impact a change in any one of these variables may have on the end-product, which is the filter yield, we should examine how these variables are interrelated. This is generally illustrated by the filter yield equation [3]:

$$L = \left[\frac{2\ Pwk}{\mu r \theta_c}\right]^{\frac{1}{2}} \qquad (8)$$

where: L = the filter yield ($ML^{-2}T^{-1}$)

P = pressure difference ($ML^{-1}T^{-2}$)

w = concentration of feed solids (ML^{-3})

k = fraction of the cycle time, θ_c, for cake formation (-)

μ = liquid viscosity ($ML^{-1}T^{-1}$)

r = specific resistance (LM^{-1})

θ_c = filter cycle time (T)

Equation (8) shows that the filter yield can be increased by increasing P and k and by decreasing r, and θ_c. Cake thickness decreases as the cycle time is reduced and the drum speed is limited by the minimum cake thickness that can be removed. The drum submergence is governed by the time required to dewater the sludge cake to the desired

moisture content. We defined specific resistance earlier and one of our earlier speakers has already derived it mathematically. Suffice it to state that Equation (8) can be derived from Darcy's law based on an analysis of liquid flowing through a porous media [3]:

$$\frac{dV}{d\theta} = \frac{P}{\mu}\frac{AK}{L} \tag{9}$$

where: $\frac{dV}{d\theta}$ = rate of flow (L^3T^{-1})

P = pressure difference ($ML^{-1}T^{-2}$)

μ = liquid viscosity ($ML^{-1}T^{-1}$)

A = surface area (L^2)

K = permeability (L^2)

L = thickness (L)

From equation (9), after integration and rearrangement of terms, it is possible to calculate the specific resistance as:

$$r = \frac{2PA^2b}{\mu w} \tag{10}$$

where: r = specific resistance (LM^{-1})

P = pressure difference ($ML^{-1}T^{-2}$)

A = filter area (L^2)

b = slope of data from Buchner Funnel test (TL^{-6})

μ = liquid viscosity ($ML^{-1}T^{-1}$)

w = weight of dry cake solids per unit volume of filtrate (ML^{-3})

To summarize it would be of interest to recall (Table 7) that vacuum filtration requires a relatively high-energy input per cubic metre of sludge processed and depending on the sludge source, dry solids concentrations of up to 30% are attainable.

The design methodology used for vacuum filter selection is illustrated by Campbell et al [6].

Positive pressure

Plate and frame filter press. Filter presses most often used for sludge dewatering are of the plate and frame or recessed plate type.

They have been used extensively in the chemical industry for difficult to dewater sludges and are extremely popular in Europe. The press consists of a set of vertical, recessed plates which are held rigidly in a frame and are pressed together between a fixed and a moving free end. A side view of a filter press is shown in Figure 27.

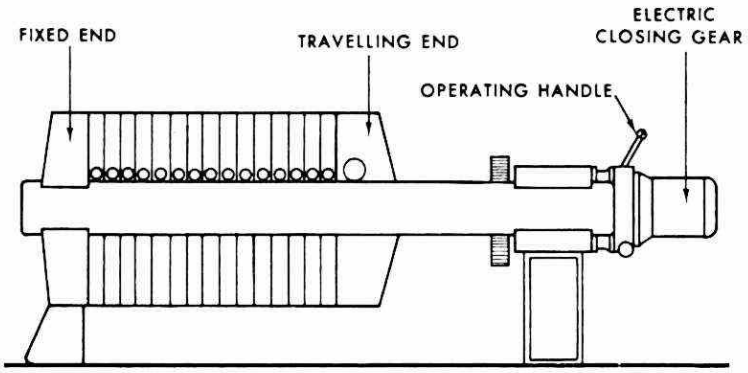


FIGURE 27. SIDE VIEW OF FILTER PRESS [16]

Filter fabrics, generally consisting of synthetic fibers, are applied to each of the two grooved plate surfaces. The sludge is fed (as shown in Figure 28) into the centre of the press and passes through feed holes at the centre of the plates along the length of the press. The water passes through the cloth and is collected by filtrate removal ducts which can either be joined from plate to plate or be separate from each plate. The solids are retained and form a cake on the cloth surface. The applied pressure differential is generally in the order of 325 kN/m^2. Experiments using pressure differentials of up to 725 kN/M^2 have produced filter cakes in excess of 50% dry solids. Individual filter plate areas can be as large as 2 m^2, with total process areas of up to 400 m^2.

The successive steps in a plate filter press operation consist of filling, filtration, filter opening and cleaning.

The advantages and disadvantages of pressure filtration can be summarized as:

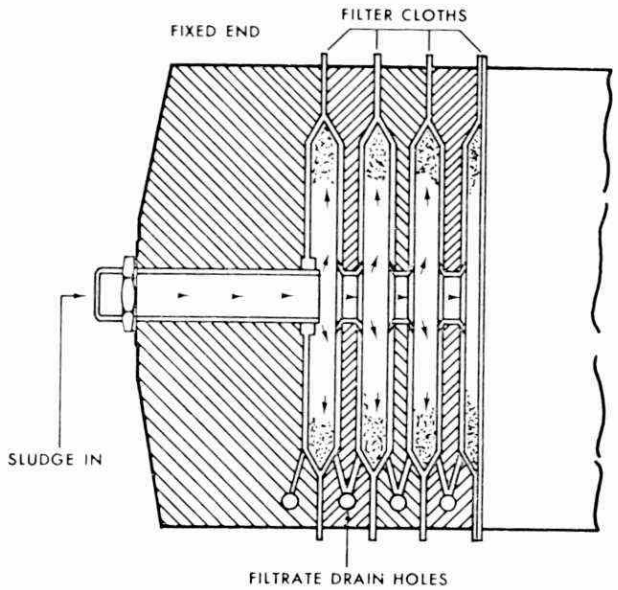


FIGURE 28. CUTAWAY VIEW OF A FILTER PRESS [16]

Advantages	Disadvantages
- high cake solids concentration	- batch operation
- improved solids capture	- high capital cost
- improved filtrate clarity	- filter cloth life limitations
- can be automated	- higher operator skill level required

The major variables in filter press system design are the chamber thickness, pressing time, pressure and sludge conditioning required to attain a specified solids concentration.

The design of filter press systems is generally based on pilot scale data since bench scale data are considered to be too inaccurate for scale-up purposes.

A design example is presented by Campbell et al [6].

Belt filter press. This positive filtration device originally developed in Europe is gaining in popularity here. A schematic of a belt filter press is shown in Figure 29. The unit consists of two continuous, separate belts. The press belt exerts pressure on the filter belt,

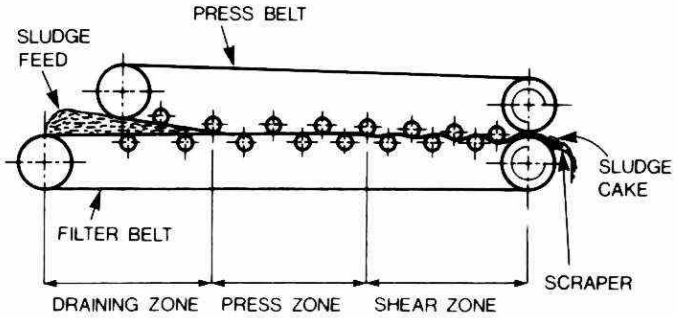


FIGURE 29. SCHEMATIC CONSTRUCTION OF THE BELT FILTER PRESS

thereby continuously dewatering the sludge which is applied to the upper face of the filter belt.

As shown in Figure 29, the belt filter press has three zones: a draining zone, a press zone and a shear zone. The construction of the belt systems is such that aside from applying pressure for water removal, shear forces are also imposed on the sludge cake. This leads to further dewatering. As shown earlier in Table 7, belt filter presses can produce sludge cakes with solids concentrations varying from 20-25% at the extremely low energy requirement of 1 kwh/m^3 of sludge throughput.

A typical belt filter press installation schematic is shown in Figure 30.

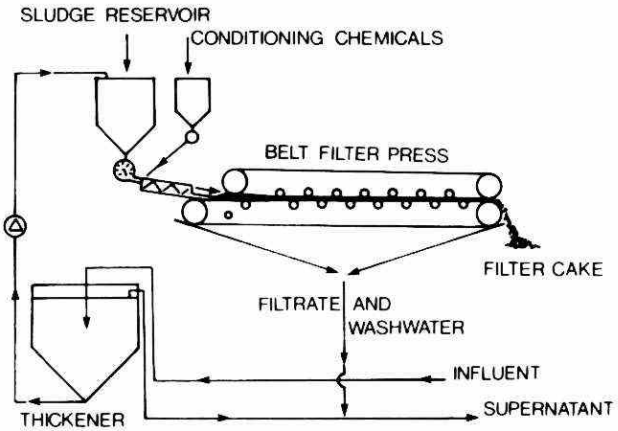


FIGURE 30. BELT-FILTER PRESS PROCESS SCHEMATIC [1]

Capillary Dewatering. One of the more recent developments in horizontal belt filter dewatering equipment is a squeegee capillary suction device as shown schematically in Figures 31 and 32. The unit consists of

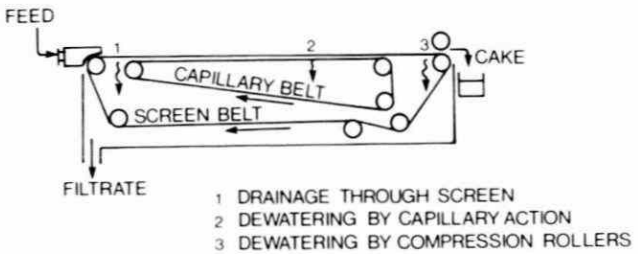


FIGURE 31. SQUEEGEE CAPILLARY SUCTION DEVICE FOR SLUDGE DEWATERING [3]

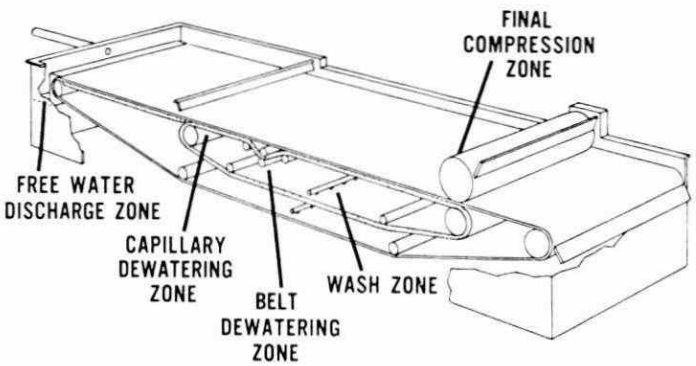


FIGURE 32. SQUEEGEE CAPILLARY SLUDGE DEWATERING UNIT [2]

two continuous belts travelling in the same direction; a screen belt and a capillary belt. Conditioned sludge is applied to the screen belt which allows for an immediate release of free water. The filtrate is collected in a trough. After this initial discharge of water (free water discharge zone) the sludge transported on the screen belt comes into contact with the capillary belt and enters a capillary dewatering zone as shown in Figure 33. Here the motive force for dewatering comes from the capillary

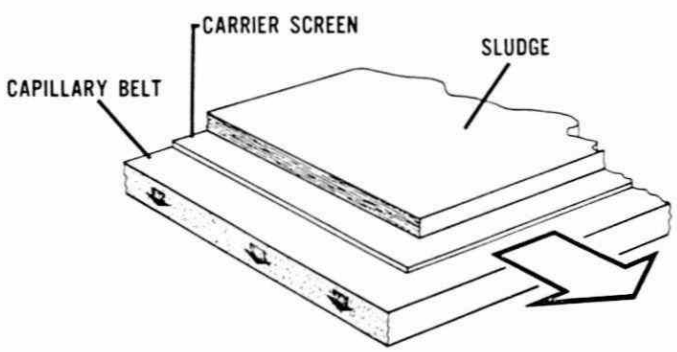


FIGURE 33. CAPILLARY DEWATERING ZONE [2]

action of the capillary belt. Along the belt are belt dewatering rolls which squeeze liquid from the saturated capillary belt by momentarily removing it from contact with the screen belt. A series of these belt dewatering rolls may exist in what is appropriately called the belt dewatering zone (Figure 34). The last stage of dewatering occurs when

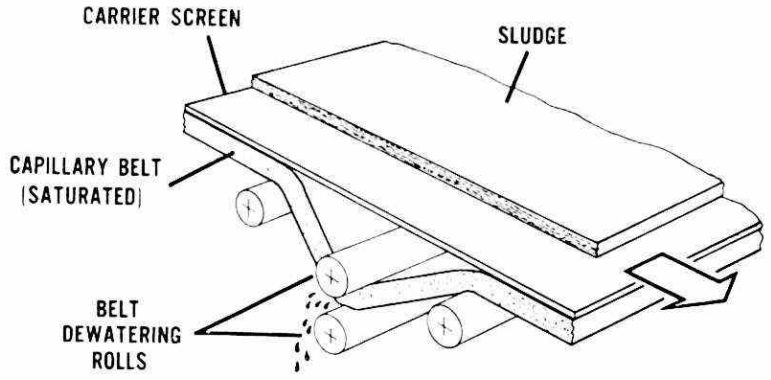


FIGURE 34. BELT DEWATERING ZONE [2]

the sludge enters the final compression zone as shown in Figure 35. The sludge cake is removed by a doctor blade and the cake drops into a discharge chute. The belt is washed automatically (wash zone) before returning for the next cycle. Little operating data and experience are available. However, experience to date has shown that this dewatering device is capable of achieving cake solids concentrations of at least 15 to 18% for activated sludge. Solids capture and overall performance are functions of coagulant dosage, sludge solids loading and screen mesh size.

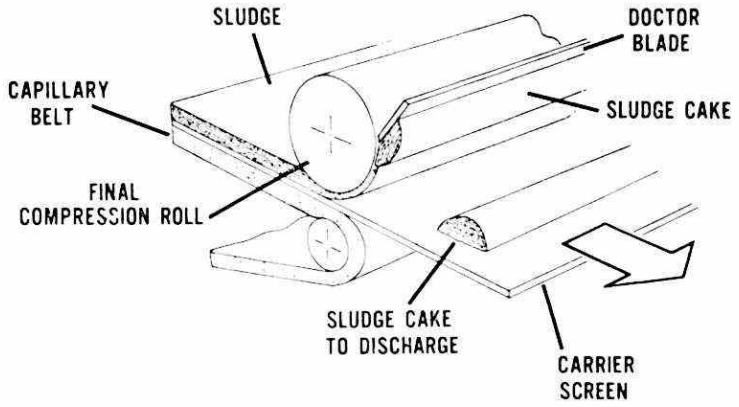


FIGURE 35. FINAL COMPRESSION ZONE [2]

Rotating gravity concentration. Another of many process variations for liquid/solid separation by filtration is the dual cell gravity filter.

As shown in Figure 36, the unit consists of two independent cells covered by a filter cloth. Sludge is pumped into the first cell, called the dewatering cell, where the water drains by gravity through the filter cloth. The partially dewatered sludge is then carried over a drive roll into the cake forming cell where additional dewatering occurs. As solids build up within the cake forming cell they discharge over the rim to a conveyor belt as a dewatered sludge cake.

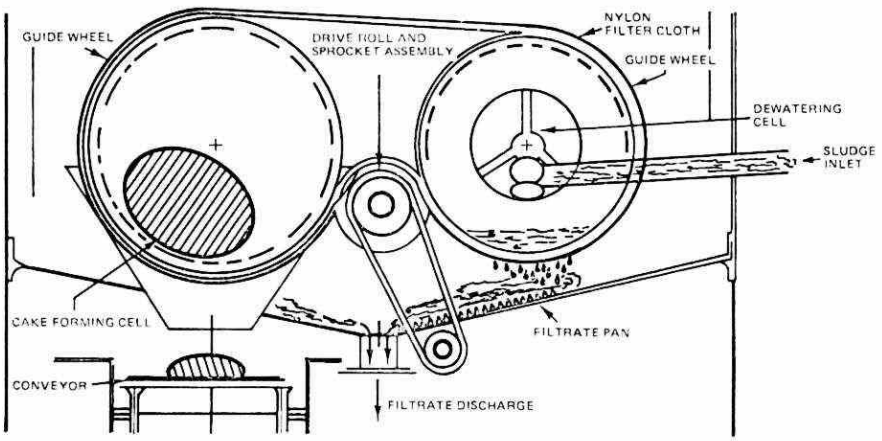


FIGURE 36. DUAL CELL GRAVITY FILTER [2]

This dewatering device offers certain advantages in that the operation is continuous; dewatering occurs by gravity without the application of external forces. As well, experience has shown that difficult to dewater sludges can be handled by the dual cell gravity filter.

As with other dewatering processes, initial solids concentration, sludge characteristics and sludge conditioning are primary variables influencing the degree of dewatering that can be attained.

Limited data show that most sludges can be dewatered to between 10 and 15% dry solids.

Dewatering by Centrifugation

A centrifuge is a liquid/solid separation device. It was first used for sludge dewatering in Germany in 1902 and tested extensively in the U.S. in the early 1920s. A centrifuge is a cylindrical vessel rotating at an angular speed containing a ring of fluid solids.

Solids are separated by subjecting them to many times the force of gravity. The acceleration generated is expressed by reference to the earth's field as a multiple of G. In the case of sludges, these gravitational forces break the particle bonding forces and remove floc and capillary water. A typical solid-bowl conveyor discharge centrifuge is shown in Figure 37. Here, sludge is pumped through a central inlet into the rotating bowl. The applied centrifugal force causes a gradation of solids from heavy to light, all hugging the bowl wall. The removal of sludge is accomplished by a rotating conveyor (scroll) inside the bowl, rotating at a slightly lower speed than the bowl. This screw action conveys the solids up to the inclined beach and out the open end. The centrate flows out at the other end of the bowl.

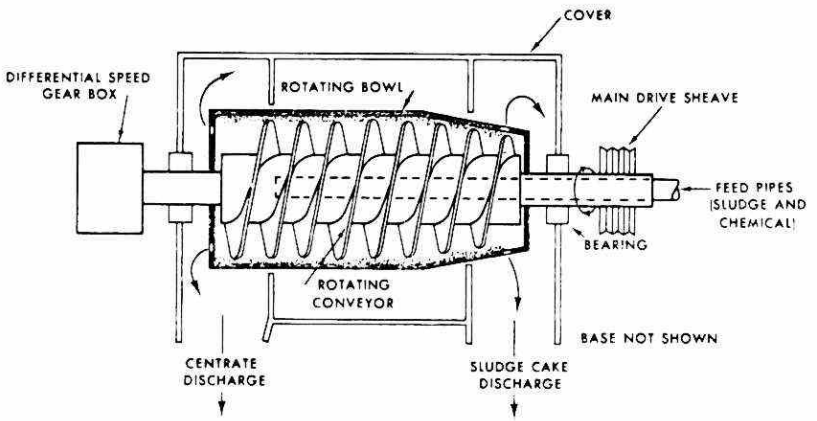


FIGURE 37. CONTINUOUS COUNTERCURRENT SOLID BOWL CONVEYOR DISCHARGE CENTRIFUGE [2]

Variables influencing the performance of centrifugation consist of machine and operational variables. Machine variables are identified in Figure 38. The effect of changing any one of the variables is illustrated in Table 8 and indicates the apparent flexibility in centrifuge design and operation. While sludge characteristics (including conditioning) are extremely important, one variable within the control of the operator is the residence time which he can control by the flow of sludge to the machine.

Figure 39 summarizes the effect of changing either machine or operational variables on solids recovery and cake solids concentration. A higher cake solids concentration is traded for a lower solids recovery.

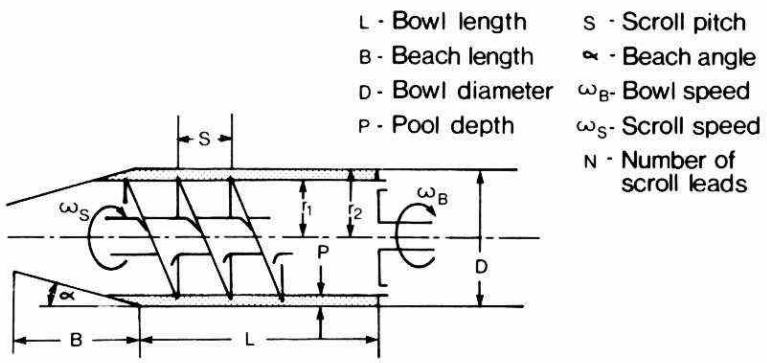


FIGURE 38. CENTRIFUGE - MACHINE VARIABLES [3]

TABLE 8. EFFECT OF CHANGING SOLID BOWL CENTRIFUGE MACHINE VARIABLES

MACHINE VARIABLE	TYPE OF CHANGE	EFFECT* ON							
		DETENTION TIME	SOLIDS RECOVERY	CAKE SOLIDS CONC.	MC IN CAKE	CENTRATE	GRAVITATIONAL FORCE	MACHINE LIFE	OPERATING COST
BOWL DIAMETER	INCREASE**	+	+	-	+				
BOWL LENGTH	INCREASE	+	+	+					
BOWL SPEED	INCREASE		+	+			+	-	+
POOL DEPTH	INCREASE	+	+	-	+				
SCROLL SPEED	INCREASE	-	-	+	-				
SCROLL PITCH	INCREASE		-		-	-			
SCROLL	WORN		-		-	-			
NUMBER OF SCROLL LEADS	INCREASE		-		-				
BEACH ANGLE	INCREASE		-	+		-			

* + increase, higher; - decrease, poorer
** (G) Constant

A considerable amount of data on the application of solid bowl centrifuges for sludge dewatering has been accumulated. For a solids recovery of 95% solids concentrations of 20 to 25% are not uncommon. Energy requirements are estimated to be approximately 2 kwh/m^3 sludge throughput (Table 7).

Other centrifuges such as the basket type (Figure 40) and disc type (Figure 41) have been recently introduced into the wastewater

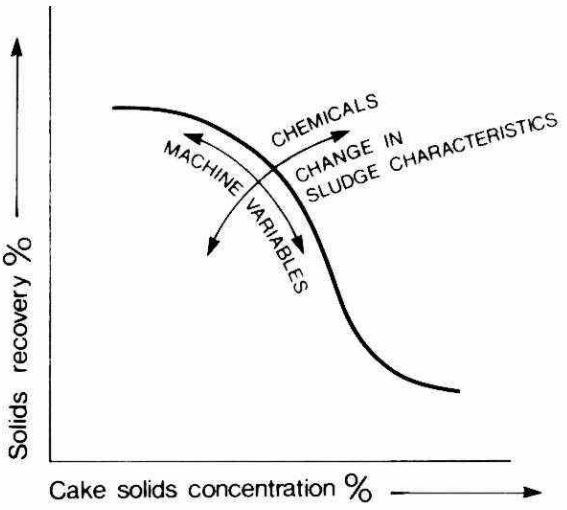


FIGURE 39. CENTRIFUGE SOLIDS RECOVERY/CAKE SOLIDS CONCENTRATION RELATIONSHIP [3]

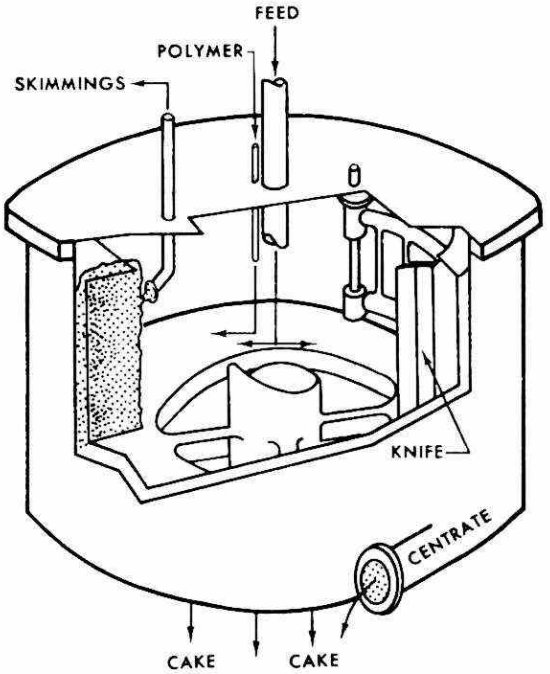


FIGURE 40. BASKET CENTRIFUGE SCHEMATIC [2]

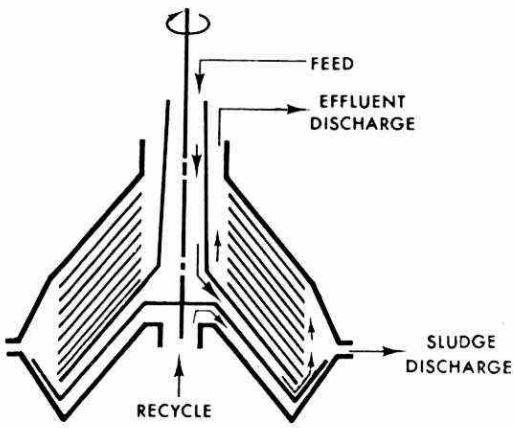


FIGURE 41. DISC TYPE CENTRIFUGE [2] SCHEMATIC

treatment field for sludge dewatering but little performance information is available at this time.

Experience has shown that a centrifuge cannot be designed for a specific application by using fundamental principles. In lieu of being able to use a centrifuge prototype for the design of a centrifuge application, practical experience combined with laboratory tests offer a reasonable alternative.

The next speaker will illustrate some of the scale-up procedures now used to design full scale centrifuge dewatering systems.

Dewatering By Drying Beds

Drying beds are a popular sludge dewatering solution for smaller communities. Essentially, sludge is applied to a specially constructed drying bed which may be of a design similar to that indicated in Figure 42.

The key factors in the design of sludge drying beds are:

- sludge drainability,
- weather conditions,
- land availability,
- labor availability.

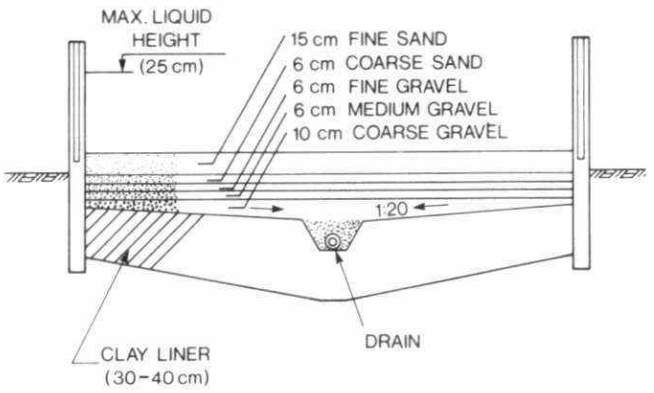


FIGURE 42. SLUDGE DRYING BED CROSS SECTION [1]

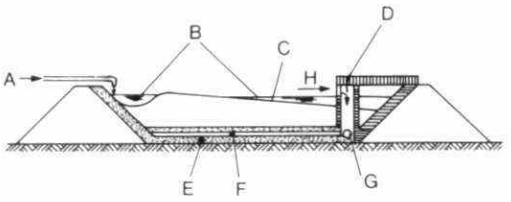
The mechanism of water removal in sludge drying is two-fold:

1. drainage of free water through the sludge:
   - by settling of solids and general compaction,
   - by formation of channels that facilitate movement of water;
2. dewatering by evaporation.

The first mechanism is responsible for reducing the water content down to 80%, whereas the second mechanism can, under favorable weather conditions, further decrease the water content to 55%.

Dewatering by Lagooning

The lagooning of sludges is a low cost, simple sludge dewatering alternative which has been used in many parts of the world. Figure 43 illustrates one type of sludge lagoon construction.



A. INFLUENT
B. WATER LEVEL
C. SLUDGE LEVEL
D. SUPERNATANT REMOVAL
E. CLAY LINER
F. UNDERDRAIN
G. SUPERNATANT RETURN LINE
H. SURFACE WATER

FIGURE 43. SLUDGE STORAGE LAGOON [1]

Prerequisites to the selection of this alternative are the availability of land and public awareness of odour problems which can occur. In many instances, dewatering occurs by evaporation. However, if the lagoons are located in cold climates, dewatering during the winter months occurs by freeze-thawing and involves the separation of water from solids due to the formation of ice crystals.

Experiences encountered by the City of Winnipeg in handling its sludge by lagooning and freeze-thawing were most recently presented at the Calgary Handling and Disposal Seminar [16].

It is hoped that a better appreciation for and understanding of the principles involved in sludge thickening, conditioning and dewatering, when reinforced by practical experiences put on a scientific basis, will inspire confidence in designing sludge handling and disposal operations.

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DESIGN CONSIDERATIONS FOR SLUDGE THICKENING AND DEWATERING PROCESSES

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INTRODUCTION

The design of sludge treatment facilities has traditionally received much lower priority than the design of treatment systems for the liquid portion of the waste. This may have been due partially to the fact that until the liquid treatment facility was in operation there was no sludge problem, and partially to the fact that while liquid discharges were regulated by government standards, sludge disposal was not. It is still a common occurrence to find flow diagrams of waste treatment systems which end with an arrow and the caption "to sludge disposal", even though sludge disposal costs may represent up to 50% of the total cost of waste treatment. In view of this, it is essential that sludge treatment design procedures generate data which will allow meaningful comparisons between various alternatives, and lead to the selection of the optimum system. The purpose of this paper is to briefly outline how design data may be obtained for several mechanical dewatering processes, and subsequently used to estimate equipment requirements and associated costs. All of the material, including tables and figures, has been extracted from the Sludge Dewatering Design Manual by Campbell et al (1978). A more detailed analysis of design procedures and cost estimation techniques is available in the manual.

DESIGN RATIONALE

Basis for Design

The design of a sludge dewatering installation can be based on either previous experience with similar sludges, or experimental data developed using the sludge in question. When sludge is not available for test purposes, as is often the case when designing a new treatment plant,

the designer must rely on whatever data is available for similar types of sludge. Under these circumstances the designer should be aware of the potential pitfalls of using average or generalized design values. If the sludge does not possess the expected dewatering characteristics the resulting system may either have excess capacity which is not desirable because of cost, or have inadequate capacity to achieve the required level of performance. Relatively small variations in sludge characteristics can significantly affect chemical conditioning costs. It is even possible that the characteristics of the actual sludge might differ to the extent where the dewatering process installed would not be applicable. The adequacy of a design based on past experience depends to a large degree on the variability of the input waste to the treatment system. Where a large percentage of the influent flow consists of a variety of industrial wastes, it may be advisable to postpone the design of sludge dewatering facilities until samples of the sludge are available.

Many sludge dewatering installations constitute either an additional phase of the treatment complex (e.g. phased construction program) or an expansion of existing dewatering facilities (e.g. due to plant expansion or modification). Sludge is usually available for test purposes and process design should be based on experimental data. Determination of general sludge characteristics may immediately eliminate some processes from further study. Subsequent bench tests and/or pilot plant operation can be used to evaluate the relative applicability of the remaining processes. Data developed in this manner will allow the designer to select the most appropriate process, to size the equipment, to specify operating conditions, to estimate conditioning requirements, and to prepare cost estimates. Without experimental data to define the boundary conditions within which the process will operate, it is impossible to design a system which adequately satisfies a given set of objectives. The design approaches presented in this paper are only applicable to situations where samples of the sludge are available for testing.

Selection of Design Parameters

The selection of appropriate design parameters is an important factor in equipment sizing. The design parameters should be dependent on both the dewatering characteristics of the sludge and the operating variables of the process. The use of liquid flow rate to a dewatering unit has been used as a basis for the design of some processes in the past but it is not recommended. This assumes, incorrectly, that the performance and capacity of a system is independent of the characteristics of the sludge. An example of an appropriate design parameter is the yield from a vacuum filter. For any set of operating conditions the filter yield is governed by the characteristics of the sludge. Alteration of either the sludge characteristics or the operating variables in such a way that the filter yield is increased will result in either an increase in the available capacity of a filter presently in operation or a decrease in the size requirements of a proposed filter.

Design Objectives

The primary objective of every sludge dewatering installation is to provide the maximum capacity and level of performance at minimum cost. The secondary objectives which determine what equipment will produce these results include the ultimate disposal options for both the sludge and the effluent, the level of thickening and clarification required, the necessary level of chemical conditioning, and the flexibility of the specific plant operating schedule. Unfortunately, due to their conflicting nature, these objectives cannot be optimized simultaneously. Increasing the flow rate to a unit in order to reduce the size of equipment required will reduce capital costs, but the performance may also deteriorate. An increase in chemical conditioning normally enhances performance but it also increases costs. The only way to arrive at a rational optimization approach is to assign priorities to the various objectives. These may be dictated by external constraints or may be the result of a trade-off between objectives. Once a set of priorities has been established the objectives with the highest level of priority are satisfied first and the remaining objectives optimized within these boundary limits. Without this type of approach the best

that can be expected is a system which is adequate but not necessarily optimum in terms of either cost or performance.

DEVELOPMENT OF DESIGN INFORMATION

The processes examined in this paper include gravity thickening, dissolved air flotation, centrifugation, vacuum filtration, plate and frame (recessed plate) pressure filtration, and filtration by belt filter presses. The design approaches outlined utilize the results of bench and/or pilot plant tests to estimate full scale equipment requirements. The data used to illustrate the design procedure for each process represents actual experimental results generated at the Wastewater Technology Centre in Burlington, Ontario as part of sludge dewatering studies carried out under the research and development program of the Canada-Ontario Agreement on Great Lakes Water Quality. All assumptions regarding the full scale flow rates and required performance levels are presented with each design example. Two aspects of design which are not considered in the examples are the optimum operating schedule and the need for reserve capacity. These factors have a significant effect on the size of equipment specified and should be based on the requirements of each individual installation. It is common practice, in plants with a design capacity of 45,500 m^3/d (10 mgd) or greater, to operate the sludge dewatering equipment on a continuous, 7 days a week basis. In this paper it has been assumed, for the purpose of illustrating design techniques only, that all equipment will operate 24 hours a day, 7 days a week, without reserve capacity. Although it is obvious that this assumption is not realistic for smaller plants in particular, it is a simple matter to adjust the hourly flow rate to compensate for the decreased operating schedule.

Gravity Thickening

Gravity thickening is often used as a preliminary and relatively low cost method of sludge volume reduction prior to digestion or dewatering. Design data is normally generated from batch settling tests. The design of gravity thickeners involves determining the critical solids loading rate to the unit. Once this and the total solids flow have been established, the required surface area of the thickener can be specified.

To obtain the required data, settling tests are conducted for a range of influent solids concentrations. The minimum container size should be 90 to 100 cm high by 20 cm in diameter, and the sludge should be slowly stirred throughout the test. A complete description of the test procedures and influencing test variables is available in the literature (Vesilind 1974). The height of the interface is plotted against elapsed time for each test to produce a series of settling curves (Figure 1). A complete set of 12 settling tests were conducted with initial solids concentrations ranging from 0.04 to 1.8%, but for clarity the results of only five tests are shown in Figure 1. The zone settling velocity determined from the initial linear portion of each curve is plotted against the sludge solids concentration on semi-log graph paper (Figure 2). The settling velocity as determined from the best fit line (method of least squares) in Figure 2, multiplied by the initial concentration gives a value for the batch flux. A plot of batch flux versus solids concentration results in a batch flux curve (Figure 3). The limiting solids flux is determined by drawing a straight line from the desired underflow concentration and tangent to the batch flux curve. The point of intersection of this line with the vertical axis gives the value of the limiting solids flux. Selection of the required surface area is based upon the following relationship (Adams and Eckenfelder, 1974):

$$A = Q_o \, C_o / G_L \qquad (1)$$

where: A = surface area (m^2)
Q_o = influent flow rate (m^3/h)
C_o = influent solids concentration (kg/m^3)
G_L = limiting solids flux (kg/m^2-h)

The flow rate of the thickened sludge underflow can be determined on the basis of the following mass balance around the thickener (Adams and Eckenfelder, 1974):

$$Q_o \, C_o = Q_u \, C_u + C_e \, (Q_o - Q_u) \qquad (2)$$

where: Q_u = underflow (m^3/h)
C_u = underflow solids concentration (kg/m^3)
C_e = supernatant suspended solids (kg/m^3)

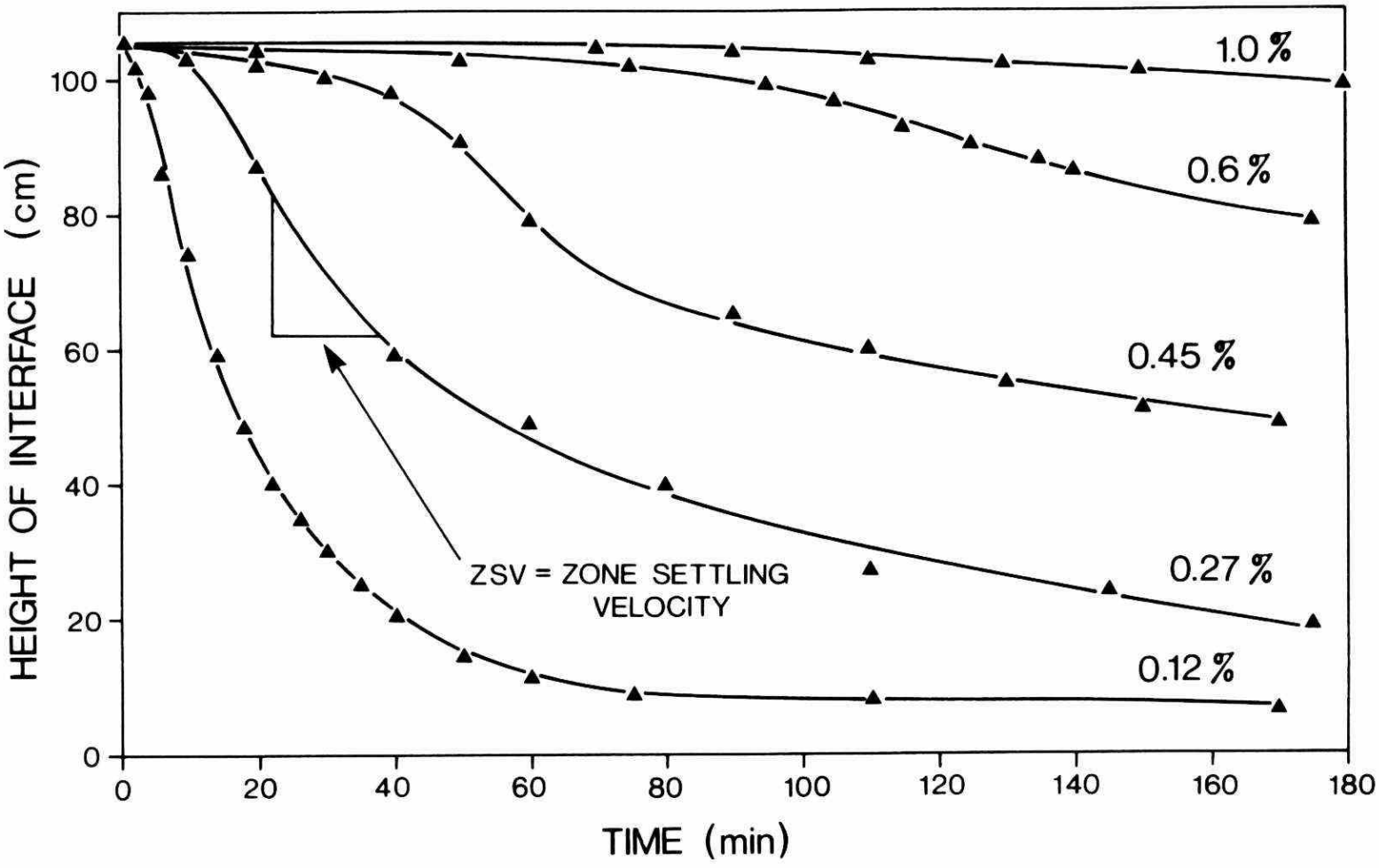

FIGURE 1. WASTE ACTIVATED SLUDGE SETTLING CURVES

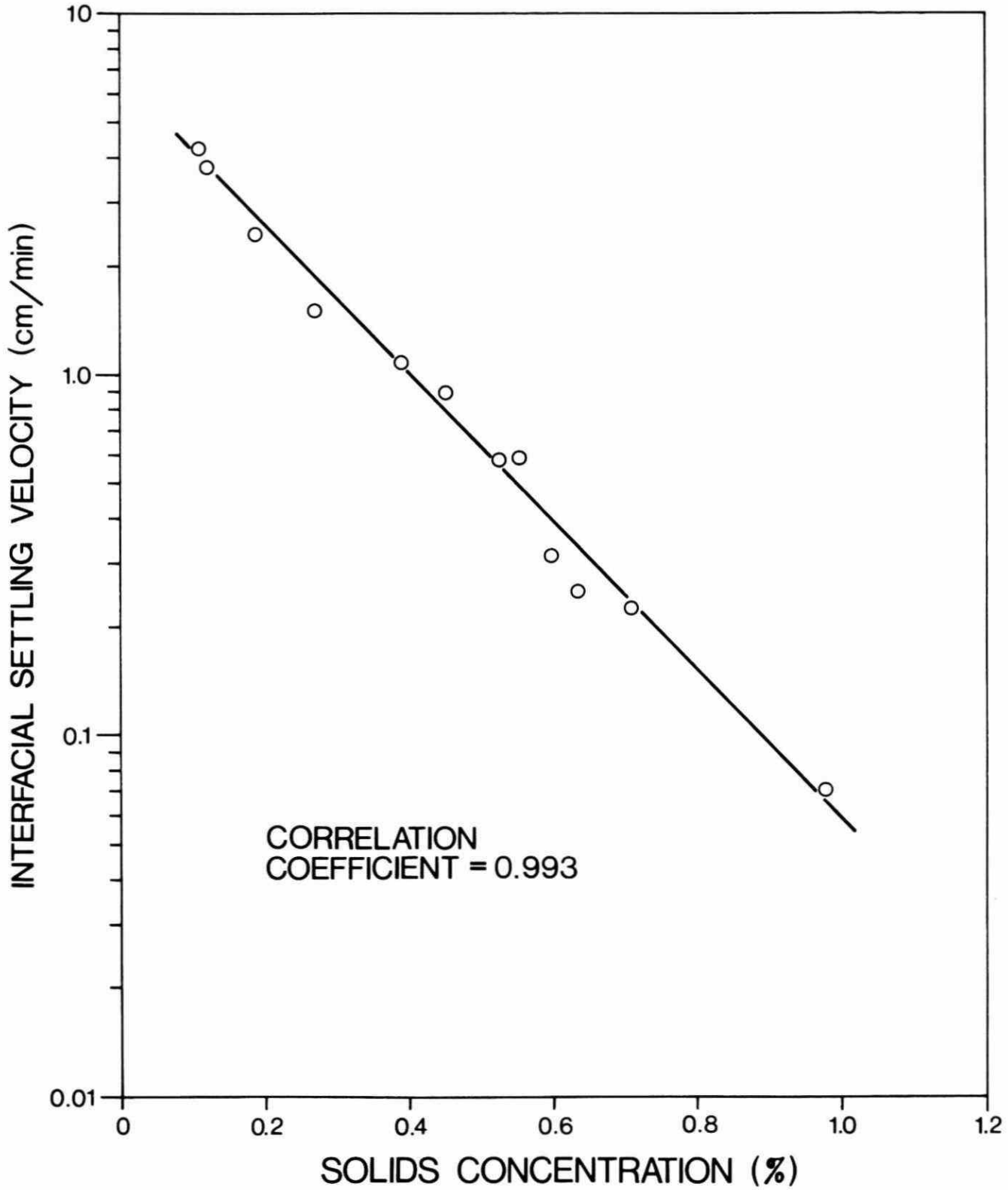

FIGURE 2. INTERFACIAL SETTLING VELOCITY VERSUS SOLIDS CONCENTRATION

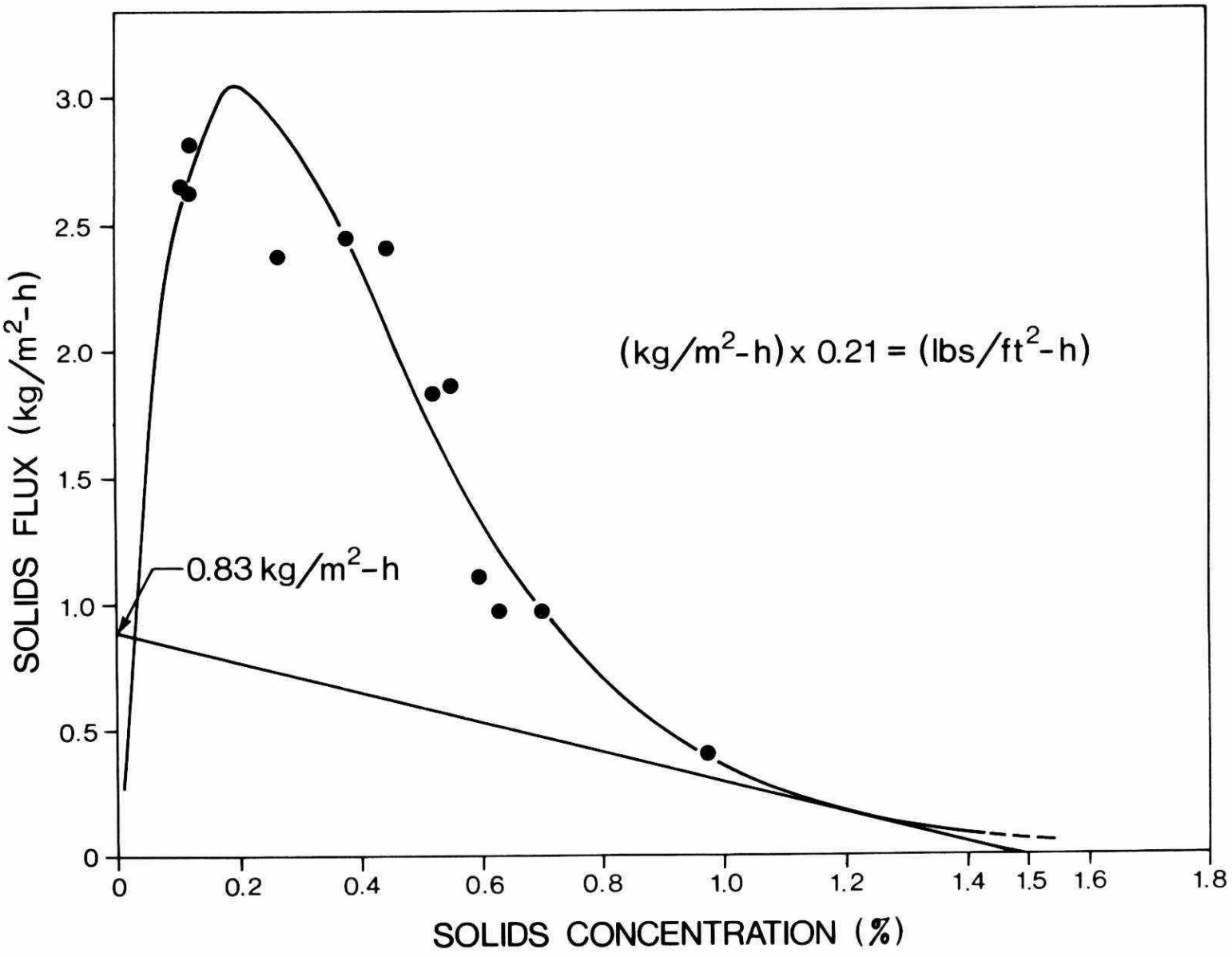

FIGURE 3. BATCH FLUX CURVE FOR WASTE ACTIVATED SLUDGE

The design of a gravity thickener is best illustrated by the following example:

SLUDGE CHARACTERISTICS

1. Waste activated sludge
2. Flow rate = 25 m^3/h (90 Igpm)
3. Influent solids concentration = 0.55%

PERFORMANCE CRITERIA

1. Underflow concentration = 1.5%
2. Supernatant suspended solids < 100 mg/L

A series of settling tests without the addition of polymer produced the results shown in Figures 1, 2, and 3. In all cases, the suspended solids of the supernatant were less than 100 mg/L. The limiting solids flux for an underflow concentration of 1.5% is determined from Figure 3.

Calculation of Surface Area:

Q_o = 25 m^3/h
C_o = 0.55% = 5.5 kg/m^3
G_L = 0.83 kg/m^2-h

Substituting into Equation 1:

$$A = \frac{25 \times 5.5}{0.83} = 166 \text{ m}^2 \ (1783 \text{ ft}^2)$$

The required thickener diameter would be 14.5 m (47.7 ft). This would normally be supplied by the next largest standard diameter. Based on experience, the depth of gravity thickeners has generally been standardized at 3 - 4 m (10 - 13 ft).

Calculation of Underflow Rate:

Q_o = 25 m^3/h
C_o = 0.55% = 5.5 kg/m^3
C_u = 1.5% = 15.0 kg/m^3
C_e = 100 mg/L = 0.1 kg/m^3

Substituting into Equation 2:

$25 \times 5.5 = 15\ Qu + 0.1\ (25 - Q_u)$

$Q_u = 9.1\ m^3/h\ (33\ Igpm)$

Pumping capacity of 9.1 m^3 (33 Igpm) would be required for sludge withdrawal.

If a higher level of performance was necessary (e.g. Cu = 4.0%) with the same sludge, the effect of polymer addition could be evaluated. This would consist of repeating the settling tests at the appropriate polymer dosages and developing a new batch flux curve for each dosage.

DESIGN SUMMARY

Flow rate	25 m^3/h (90 Igpm)
Initial Solids Concentration	0.55%
Solids Loading (flux)	0.83 kg/m^2-h (0.17 lbs/ft^2-h)
Polymer Addition	None
Underflow Concentration	1.5%
Underflow Rate	9.1 m^3/h (33 Igpm)
Supernatant Suspended Solids	<100 mg/L
Surface Area	166 m^2 (1783 ft^2)
Thickener Diameter	14.5 m (47.7 ft)
Thickener Depth	3 - 4 m (10 - 13 ft)

Dissolved Air Flotation

Dissolved air flotation is widely accepted as a practical technique for separating oils and greases from a liquid, and as a means of thickening activated sludge and flocculant chemical sludges. Both bench scale and/or pilot scale tests can provide information for the design of dissolved air flotation (DAF) units. The required surface area is determined on the basis of the solids loading to the DAF unit. The maximum solids loading at which the desired performance can be achieved will be affected by the air/solids ratio and the polymer dosage.

Batch flotation tests can be carried out using either a two or a three cylinder apparatus. The procedures for these two tests are described by Eckenfelder and Ford (1970), and by Wood and Dick (1973),

respectively. The batch test is an effective method of evaluating the effect of air/solids ratio and polymer dosage on the rise rates, the float solids concentration, and the effluent suspended solids. Theoretically it is possible to use rise rates to generate a flux curve in a similar manner to that for gravity thickening, but due to the difficulties inherent in producing acceptable flux curves this approach has not been used. Since the flux curve is the only method of obtaining a measure of the solids loading rates under batch conditions, it is not recommended that DAF systems be designed on the basis of batch data only.

In order to determine the maximum allowable solids loading for any given set of conditions, it is usually necessary to operate a continuous flow pilot plant. The most common pilot plants have surface areas ranging from 0.09 to 1.4 m^2 (1 to 15 ft^2). Previous studies shown that comparable performance could be achieved on three sizes of DAF units (0.09 m^2, 1.4 m^2 and 37.2 m^2) operating on the same sludge (Campbell and LeClair, 1974). An example of how pilot scale data can be used to evaluate the process and estimate full scale size requirements is shown as follows:

SLUDGE CHARACTERISTICS

1. Waste activated sludge
2. Flow rate = 25 m^3/h (90 Igpm)
3. Influent solids concentration = 1% = 10 kg/m^3
4. Solids flow rate = 25 m^3/h x 10 kg/m^3
   = 250 kg of dry solids/h

PERFORMANCE CRITERIA

1. Float solids = 4%
2. Suspended solids recovery = 99%

A 0.09 m^2 DAF pilot plant was operated to determine the effect of solids loading, polymer dosage, and air/solids ratio on the performance of the unit. An effluent with less than 30 mg/L of suspended solids was achieved under all operating conditions. The effect of the operating variables on the float solids is shown in Figure 4.

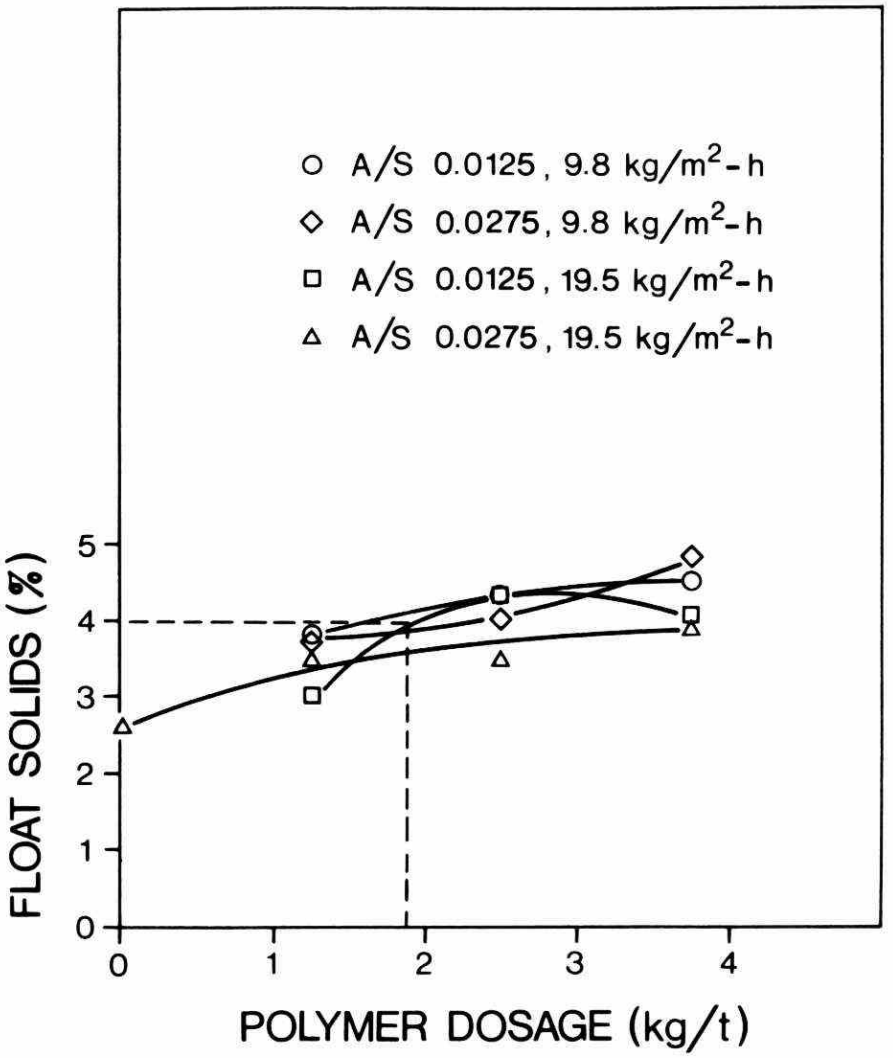

FIGURE 4. THICKENING PERFORMANCE OF DISSOLVED AIR FLOTATION PILOT PLANT

The optimum selection of operating variables should maximize solids loading and minimize polymer dose and air/solids ratio. A solids recovery of 99% would be satisfied under all conditions tested. Figure 4 indicates that the required float solids of 4% could be most economically obtained under the following conditions:

Solids loading = 19.5 kg/m^2-h (4 lbs/ft^2-h)
Polymer dosage = 1.85 kg/t (3.7 lbs/ton)
Air/solids ratio = 0.0125

Based on solids loading the required surface area is:

$$\frac{250 \text{ kg/h}}{19.5 \text{ kg/m}^2\text{-h}} = 12.8 \text{ m}^2 \text{ (137 ft}^2\text{)}$$

Since DAF units are normally prefabricated in standard sizes, a unit of 14 m^2 (150 ft^2) would be selected. The effective solids loading would be decreased to:

$$\frac{250 \text{ kg/h}}{14 \text{ m}^2} = 17.8 \text{ kg/m}^2\text{-h (3.65 lbs/ft}^2\text{-h)}$$

This solids loading falls within the suggested operating range of 9.8 - 19.5 kg/m^2-h (2 - 4 lbs/ft^2-h) (EPA, 1974).
The hydraulic loading to the unit would be:

$$\frac{25 \text{ m}^3\text{/h}}{14 \text{ m}^2} = 1.8 \text{ m}^3\text{/hr-m}^2 \text{ (0.6 Igpm/ft}^2\text{)}$$

This is below the suggested maximum overflow rate for thickening applications of 2.4 m^3/hr-m^2 (0.8 Igpm/ft^2) (EPA, 1974).

DESIGN SUMMARY

Flow rate	25 m^3/h (90 Igpm)
Influent Solids Concentration	1%
Solids Flow Rate	250 kg/h (550 lbs/h)
Solids Loading	17.8 kg/m^2-h (3.65 lbs/ft^2-h)
Polymer Dosage	1.85 kg/t (3.7 lbs/ton)
Air/Solids Ratio	0.0125
Hydraulic Loading	1.8 m^3/hr-m^2 (0.6 Igpm/ft^2)

Surface Area	14 m^2 (150 ft^2)
Float Solids	4%
Effluent Suspended Solids	30 mg/L

Centrifugation

In recent years the process of centrifugation has gained wide acceptance in the wastewater field. The three types used are the solid bowl centrifuge, the basket centrifuge, and the disc centrifuge. Because the disc centrifuge has only limited application to wastewater sludges, design procedures will not be developed for this type of unit.

Bench tests for centrifugation have not been developed to the point where they can be used to predict size requirements of full scale machines. Operation of a pilot plant centrifuge is the only available means of generating reliable design data. Solid bowl conveyor centrifuges are available in a wide range of sizes. Selection of the optimum size of machine is based on determining the liquid and solids handling capacity required to dewater the slurry. Imperforate bowl basket centrifuges recommended for wastewater sludge applications are often available in only one size from each manufacturer. The capacity of the full scale machine is established by operating a pilot scale unit on the test sludge. Equipment selection then becomes a problem of determining the number of machines required.

A wide variety of centrifuge bench tests which range from shaking a sample of conditioned sludge in a beer bottle and observing the stability of the floc (Schultz, 1957), to monitoring the interfacial subsidence rate using a laboratory centrifuge and strobe light (Vesilind, 1974), have been reported in the literature, but have not been used for design purposes. The primary uses of bench tests have been to evaluate the feasibility of centrifugation qualitatively, and to select the type and dosage of polymer required. Preliminary data generated by a test developed at the Wastewater Technology Centre has indicated that this test may have potential for use, both as a design tool and as a polymer selection aid. In this test fifty-millilitre samples of digested lime sludge were spun on a bench centrifuge at 3500 rpm for 2 minutes. A portion of the sludge cake was scrolled out of the tube using an auger

drill bit while the tube was held at a 45° angle. Solids analyses were done immediately on the liquid remaining in the tube before the dispersed solids had a chance to resettle. One measure of the cake solids concentration was determined by solids analysis on the scrolled portion, while another measure was obtained on the basis of the cake volume before scrolling (Vesilind, 1973) and the two values averaged. Correlation between the bench test and a 15 x 30 cm (6 x 12 in) pilot scale solid bowl centrifuge is shown in Figure 5. It is anticipated that the effect of flow rate could be reproduced by altering the spin time on the bench centrifuge. The use of the test as a method for determining suitable polymers and estimating required dosages is illustrated in Figure 6. Assuming the costs of the two polymers are equal, polymer A is superior to polymer B in terms of both solids recovery and cake concentration.

Solid bowl centrifugation

Pilot scale solid bowl centrifuges are normally operated to determine the effect of feed rate, bowl speed, pool depth, conveyor differential speed, and polymer dosage on the performance of the unit. This data will establish the operating conditions required to achieve the desired level of performance. Scale-up to full size is then based on solids and liquid handling capacities.

The theoretical hydraulic capacity factor (cm^2), referred to as sigma (Σ), can be determined from the following equation (Vesilind, 1974):

$$\Sigma = \frac{V\,\omega^2}{g\,\ell n\frac{r_2}{r_1}} \qquad (3)$$

where: V = centrifuge pool volume,

ω = angular velocity of centrifuge bowl,

g = acceleration due to gravity,

r_1 = radius from centerline to the liquid surface in the centrifuge bowl,

r_2 = radius from centerline to the inside wall of the centrifuge bowl.

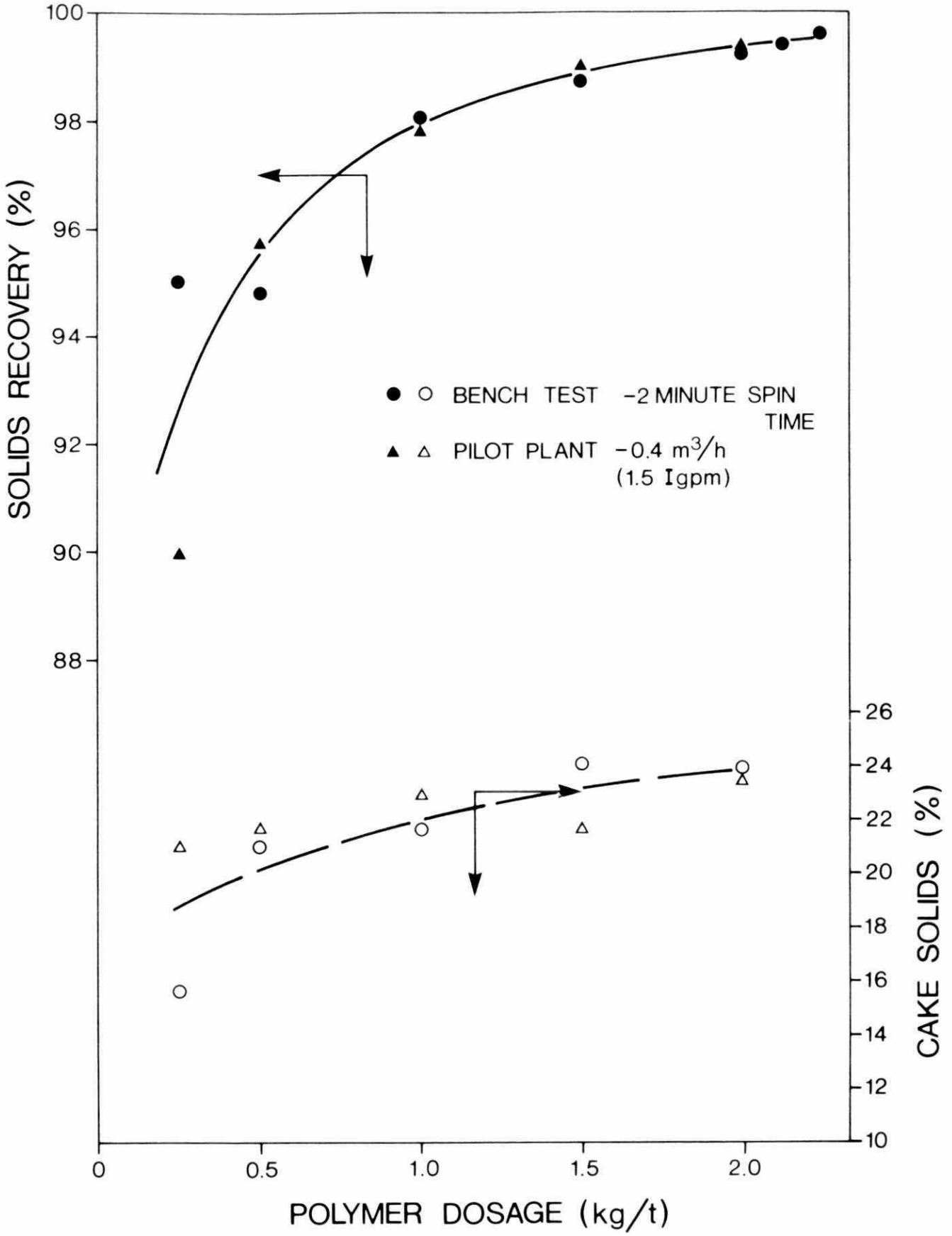

FIGURE 5. COMPARISON OF BENCH TEST PREDICTION AND PILOT PLANT PERFORMANCE OF A SOLID BOWL CENTRIFUGE

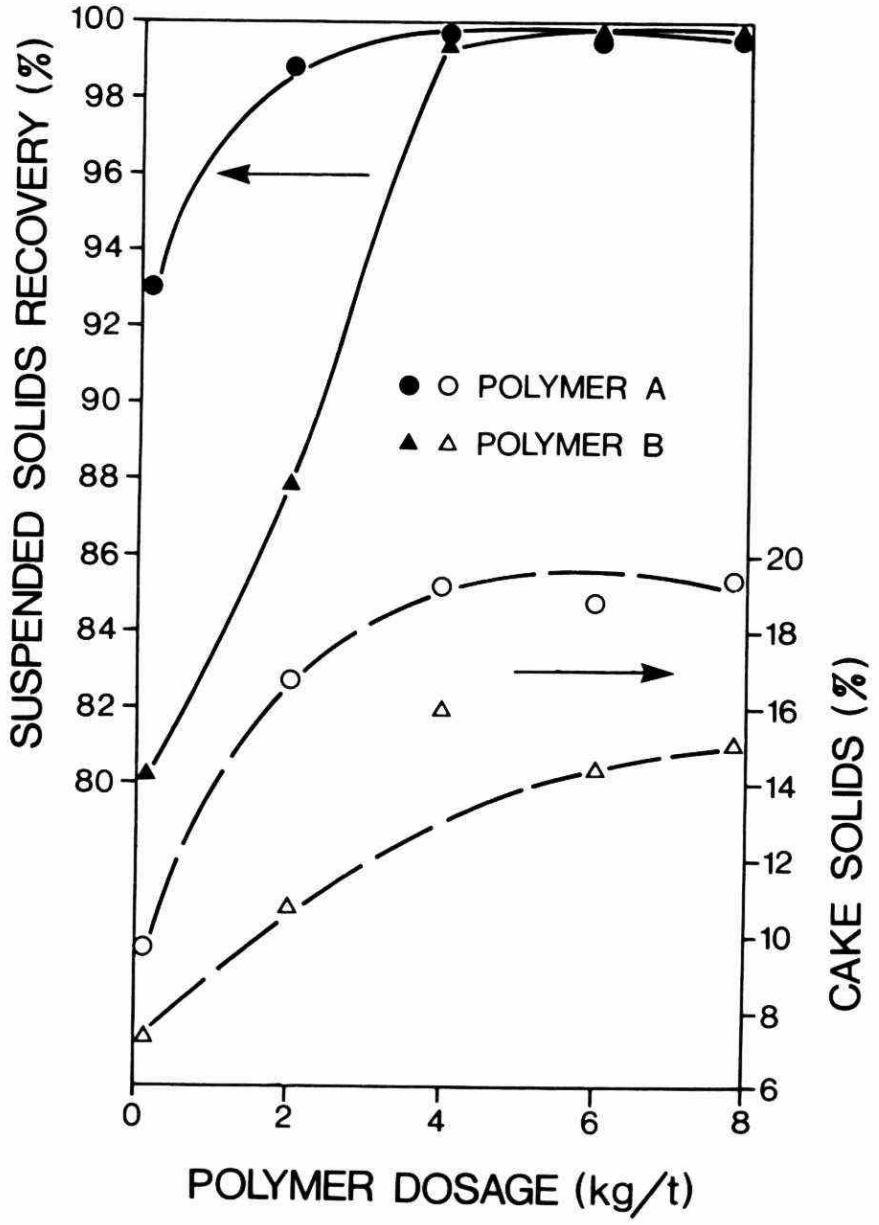

FIGURE 6. BENCH TEST PREDICTION OF SOLID BOWL CENTRIFUGE PERFORMANCE

Scale-up is based on the assumption that when the ratio of hydraulic flow rate (Q_H) to the theoretical hydraulic capacity factor (Σ) is the same for two geometrically similar but different sized machines, then the performance of the two machines will be similar for a given slurry (Vesilind, 1974). The scale-up relationship is as follows:

$$\frac{Q_{HP}}{\Sigma_P} = \frac{Q_{HF}}{\Sigma_F} \tag{4}$$

where: Q_{HP} and Q_{HF} = hydraulic flow rate (m^3/h) of the pilot scale and full scale units, respectively,

Σ_P and Σ_F = hydraulic capacity factors (cm^2) of the pilot scale and full scale units, respectively.

The theoretical solids handling capacity (m^3/h), referred to as beta (β), can be determined from the following relationship (Vesilind, 1974):

$$\beta = \pi \, \Delta\omega \, D \, S \, N \, Z \tag{5}$$

where: $\Delta\omega$ = differential speed between scroll and bowl,

D = bowl diameter,

S = scroll blade pitch,

N = number of leads on the scroll,

Z = pool depth.

Scale-up is based on the assumption that when the ratio of solids flow rate (Q_S) to the theoretical solids handling capacity (β) is the same for two geometrically similar but different sized machines, then the performance of the two machines will be similar for a given slurry (Vesilind, 1974). The scale-up relationship is as follows:

$$\frac{Q_{SP}}{\beta_P} = \frac{Q_{SP}}{\beta_F} \tag{6}$$

where: Q_{SP} and Q_{SF} = solids flow rate (kg/h) to the pilot scale and full scale units, respectively,

β_P and β_F = solids handling capacity (m^3/h) of the pilot scale and full scale units, respectively.

The best design procedure is to develop full scale requirements on the basis of both hydraulic and solids loading considerations. The limiting design would govern machine selection. In most wastewater applications, the systems are generally governed by hydraulic capacity and a design based on sigma values is sufficient. If very dense or very concentrated feed sludges are encountered, the design may be limited by the solids handling capacity and scale-up should be conducted using both methods. The use of the sigma method of scale-up can be illustrated by the following example:

SLUDGE CHARACTERISTICS

1. Primary alum sludge
2. Flow rate = 25 m^3/h (90 Igpm)
3. Feed solids concentration = 6%

PERFORMANCE CRITERIA

1. Cake solids = 16%
2. Solids recovery = 99%

A series of experimental runs on a 15.2 x 30.5 cm (6 x 12 in) pilot scale centrifuge produced the results shown in Figure 7. Due to the characteristic light fluffy nature of alum flocs, a deep pool (1.6 cm) and a relatively low centrifugal force (1360 x G or 4000 rpm) were preselected before testing. The performance criteria could be satisfied (Figure 7), under the following operating conditions:

Flow rate = 0.68 m^3/h (2.5 Igpm)
Scroll differential speed = 10.5 rpm
Polymer dosage = 2.5 kg/t (5.0 lbs/ton)

For the pilot scale centrifuge it has been determined (Campbell et al, 1978), using Equation 3 that:

$\Sigma_P = 0.16 \times 10^7 \text{ cm}^2$

The remaining scale-up variables are as follows:

$Q_{HP} = 0.68 \text{ m}^3/h$

$Q_{HF} = 25.0 \text{ m}^3/h$

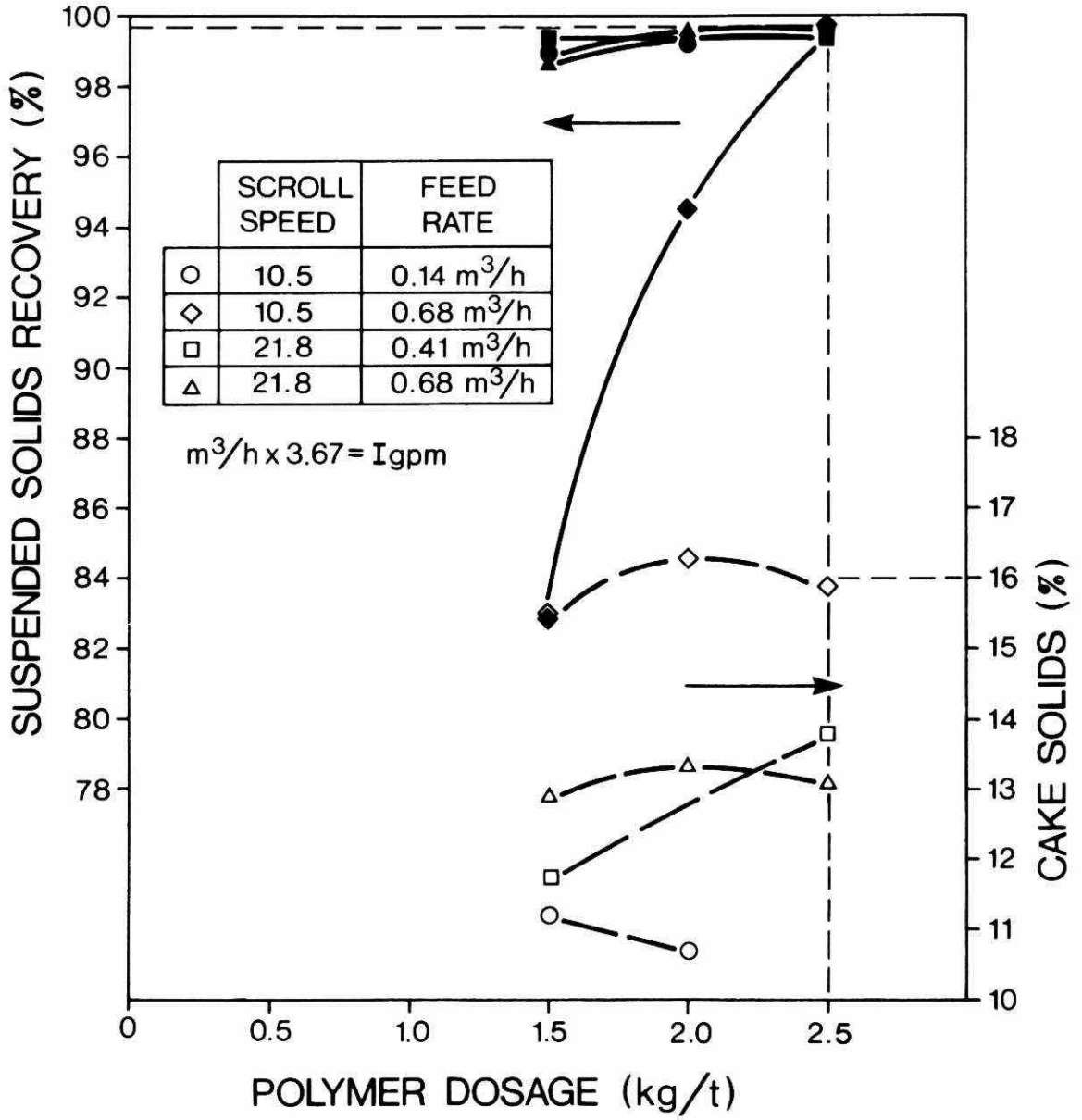

FIGURE 7. PERFORMANCE OF PILOT PLANT SOLID BOWL CENTRIFUGE (15.2 x 30.5 cm)

Substituting into Equation 4:

$$\Sigma_F = \frac{25.0 \times 0.16 \times 10^7}{0.68} = 5.9 \times 10^7 \text{ cm}^2$$

The full scale machine selected must have a theoretical hydraulic capacity factor of at least 5.9×10^7 cm^2 in order to achieve the specified performance criteria. Selection of the actual centrifuge model would normally be made in consultation with the manufacturer. The sigma value determined above, also represents a rational design parameter on which to base preliminary cost estimates.

DESIGN SUMMARY

Flow Rate	25 m^3/h (90 Igpm)
Feed Solids Concentration	6%
Scroll Differential Speed	10.5 rpm
Centrifugal Force	1360 x G
Hydraulic Capacity Factor (Σ)	5.9×10^7 cm^2
Polymer Addition	2.5 kg/t (5.0 lbs/ton)
Cake Solids	16%
Solids Recovery	99%

Basket centrifugation

A pilot scale basket centrifuge can be used to evaluate the effect of feed rate, bowl speed, and polymer dosage on the performance of the unit. Sigma values can be calculated for the basket centrifuge and a scale-up procedure similar to that outlined for the solid bowl centrifuge used. The sigma concept is based on the assumption of ideal flow conditions but the flow within a basket centrifuge does not satisfy this criterion. As a result manufacturers have, through experience, developed correction factors to compensate for the non-ideal conditions present. The use of sigma to scale up basket centrifuges, without access to the correction factors, is not recommended. A good approximation of the full scale capacity required can be developed based on sludge densities (wet and dry) and bowl volumes. The following example will illustrate this procedure:

SLUDGE CHARACTERISTICS

1. Waste activated sludge
2. Flow rate = 25 m^3/h (90 Igpm)
3. Feed solids concentration = 0.9%

PERFORMANCE CRITERIA

1. Cake solids = 10%
2. Solids recovery = 99%

A series of tests on a 35.6 x 15.2 cm (14 x 6 in) basket centrifuge produced the results shown in Figure 8. Bowl speed (2750 rpm, 1500 x G) was based on the manufacturer's recommendations and was not a test variable. The performance criteria could be satisfied (Figure 8), under the following conditions:

Flow rate = 0.41 m^3/h (1.5 Igpm)
Polymer dosage = 1.25 kg/t (2.5 lbs/ton)

The useable volume of the pilot centrifuge basket was approximately 0.0085 m^3. A full scale model, 122 x 76 cm (48 x 30 in), recommended by the manufacturer for wastewater sludges, has a useable volume of approximately 0.34 m^3. The scale-up factor based on bowl volume would be:

0.34/0.0085 = 40/1

Based on consideration of sludge density, it can be shown (Campbell et al, 1978) that to obtain a cake solids concentration of 10% with the full scale machine, the volume of wet sludge processed per cycle would be 3.9 m^3. Flow rate can be scaled up on the basis of bowl volume ratios such that:

Full scale flow rate = 40 x 0.41 m^3/h
= 16.4 m^3/h

Assuming downtime at the end of each cycle is 2.5 minutes, the average capacity of the machine will be 14 m^3/h of wet sludge (Campbell et al, 1978).

$$\text{Number of machines required} = \frac{25\ m^3/h}{14\ m^3/h} = 1.78$$

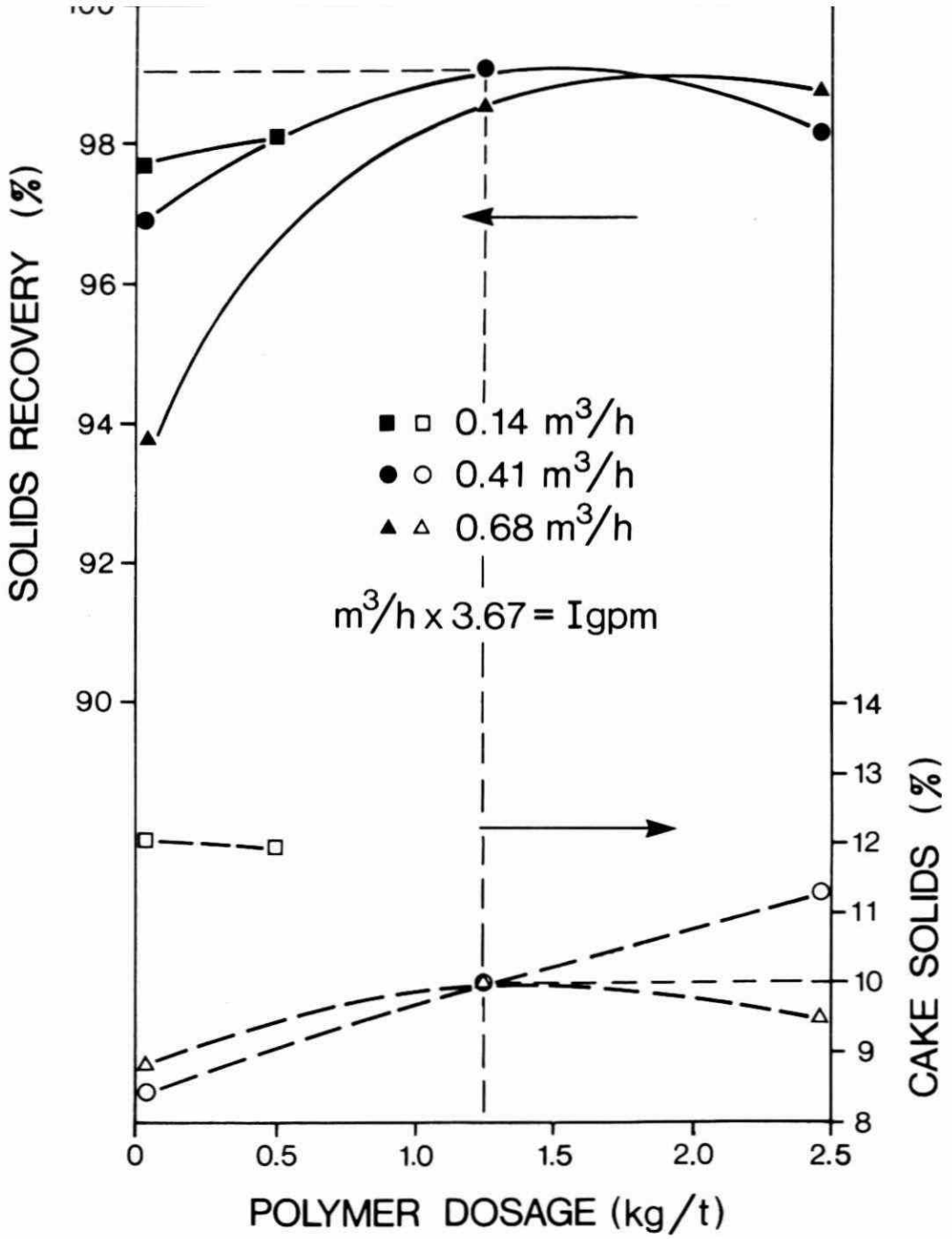

FIGURE 8. PERFORMANCE OF PILOT SCALE BASKET CENTRIFUGE (35.6 x 15.2 cm)

The installation of two machines would provide a measure of reserve capacity.

DESIGN SUMMARY

Flow Rate	25 m^3/h (90 Igpm)
Feed Solids Concentration	0.9%
Number of Centrifuges	2
Size of Bowl	122 x 76 cm (48 x 30 in)
Centrifugal Force	1500 x G
Polymer Dosage	1.25 kg/t (2.5 lbs/ton)
Maximum Flow Rate/Unit	16.4 m^3/h (60 Igpm)
Cake Solids	10%
Solids Recovery	99%

Vacuum Filtration

Vacuum filtration is one of the oldest methods of mechanically dewatering sludge from a sewage treatment plant. Vacuum filters can be designed either from bench test data or on the basis of pilot plant operation. Regardless of the method used to obtain the data, the design procedure involves determining the maximum filter yield that can be achieved under the optimum set of operating conditions. This value can in turn be related to the vacuum filter surface area required.

The bench tests commonly used for predicting filter operation are the capillary suction time test (CST), the Buchner funnel test, and the leaf filter test. All three tests provide a measure of the filtration characteristics of a sludge.

The CST (Baskerville and Gale, 1968) provides a measure of the relative dewaterability of a sludge and is most applicable for the evaluation of conditioning chemicals and methods. A good correlation between CST and specific resistance can be obtained for most sludges. The CST is used primarily for process monitoring as opposed to design.

The Buchner funnel test can be used to determine the specific resistance, the coefficient of compressibility, and to predict filter yield (Eckenfelder and Ford, 1970). It has been extensively used as a method of determining sludge conditioning requirements despite the fact that it can be a very time consuming test and requires considerable data

manipulation. Filter yields based on Buchner funnel data have been shown to give predictions within 30% of the measured yields (Gale and Baskerville, 1970). A potential problem associated with using Buchner funnel data for design purposes is that the test can not evaluate the pick-up characteristics of the sludge. The possibility of a sludge having a relatively low specific resistance without the necessary physical characteristics to ensure formation of a cake on the filter, is greater with polymers than with inorganic chemicals.

The leaf filter test provides the best approximation of actual filter operation of the three tests described. The leaf filter test can be used to evaluate the effect of conditioning, cycle time, ratio of form to dry time, pressure, and filter media on the yield of the filter. The filter yield can be calculated according to the following equation:

$$\text{filter yield} = \frac{\text{weight of dry cake x number of cycles/hour}}{\text{filter area of the leaf}} \ (\text{kg/m}^2\text{-h}) \quad (7)$$

To determine the optimum set of operating conditions it is possible to use a vacuum filter performance factor (PF) where:

$$PF = \frac{\text{conditioning cost}}{\left(\frac{\text{cake solids}}{\text{feed solids}}\right) (\text{filter yield}) (\text{recovery})} \quad (8)$$

The optimum set of conditions are those which result in the lowest value for the performance factor (Cohen and Fullerton, 1975). The utility of a performance factor can be illustrated by the following example:

SLUDGE CHARACTERISTICS

1. Digested sludge (elutriated)
2. Flow rate = 25 m^3/h (90 Igpm)
3. Feed solids concentration = 5.7% (57 kg/m^3)
4. Dry solids flow = 25 m^3/h x 57 kg/m^3
   = 1425 kg/h (3135 lbs/h)

PERFORMANCE CRITERIA

1. Solids recovery $\geq$ 95%
2. Minimize performance factor.

A summary of the leaf filter test results are shown in Table 1. The dosage of ferric chloride (6%) was based on the dewatering records of the plant where the sludge sample was obtained. All tests achieved a solids recovery level of 95 to 97% and because of the limited range, this variable was not included in the calculation of the performance factor. Examination of Table 1 indicates the lowest performance factor was 0.166. This was obtained under the following conditions:

Conditioning = 6% $FeCl_3$, 9% lime
Cycle time = 5 min
Filter media = nylon, low porosity

The corresponding cake solids and filter yield were 17.6% and 30.0 kg/m^2-h respectively. The required surface area is:

$$\frac{1425 \text{ kg/h}}{30.0 \text{ kg/m}^2\text{-h}} = 47.5 \text{ m}^2 \text{ (511 ft}^2\text{)}$$

A factor of 0.8 is commonly used to scale up from bench test data to full scale operation. The required surface areas is:

$$\frac{47.5}{0.8} = 59.4 \text{ m}^2 \text{ (640 ft}^2\text{)}$$

The development of a summary of results also allows the designer to evaluate the flexibility of the design. Using the filter designed above, it is possible to increase the capacity approximately 20%, by doubling the lime dosage from 9 to 18% and decreasing the cycle time from 5 to 1.5 min/cycle (Table 1). The performance factor of 0.189 under these conditions is not the optimum but is still the third lowest of all test conditions.

DESIGN SUMMARY

Flow Rate	25 m^3/h (90 Igpm)
Feed Solids Concentration	5.7%
Solids Flow Rate	1425 kg/h (3135 lbs/h)
Filter Area	59.4 m^2 (640 ft^2)

TABLE 1. LEAF FILTER TEST RESULTS[1]

Filter Cloth	$FeCl_3$ %	Lime %	Cycle Time min/cycle	Cake Solids %	Filter[2] Yield kg/m^2-h	Chemical[3] Cost $/metric ton	Vacuum Filter Performance Factor
Nylon, Low Porosity	6	6	5	17.3	16.8	14.04	.275
	6	9	5	17.6	30.0	15.36	.166*
"	6	9	3	16.7	31.1	15.36	.169
"	6	9	1.5	16.3	19.9	15.36	.270
"	6	12	5	16.9	17.6	16.68	.320
"	6	12	3	16.5	29.3	16.68	.197
"	6	12	1.5	15.2	13.3	16.68	.470
"	6	18	5	17.8	17.1	19.32	.362
"	6	18	3	17.1	19.8	19.32	.325
"	6	18	1.5	16.4	35.6	19.32	.189*
Nylon, High Porosity	6	9	5	18.5	10.4	15.36	.455
	6	9	3	17.4	11.6	15.36	.434
"	6	12	5	18.9	14.4	16.68	.349
"	6	12	3	16.5	20.9	16.68	.276
"	6	12	1.5	15.6	30.1	16.68	.203
"	6	18	5	20.6	19.4	19.32	.275
"	6	18	3	17.9	20.4	19.32	.302
"	6	18	1.5	15.9	24.8	19.32	.279
Coil Leaf Filter	6	12	5	17.5	16.4	16.68	.331
	6	12	3	16.6	23.9	16.68	.239
"	6	12	1.5	15.2	22.1	16.68	.283

[1]Feed Solids = 5.7%

[2]kg/m^2 x 0.205 = lbs/ft^2-h

[3]December 1975

*Refer to text

Cycle Time	5 min/cycle
Filter Media	Nylon, low porosity
Conditioning	6% $FeCl_3$, 9% lime
Filter Yield	30 kg/m^2-h (6.15 lbs/ft^2-h)
Cake Solids	17.6%
Solids Recovery	95 to 97%

Pilot plant operation is not normally required for vacuum filter design but it does provide useful information on the possibility of operational problems. A sludge which is very difficult to dewater should be pilot tested to accurately evaluate pickup and discharge characteristics of the cake under continuous flow operation.

Pressure Filtration

Pressure filtration has been widely used for many years in the chemical process industry for solid-liquid separation. It has been used extensively in Europe for dewatering wastewater sludges and is gaining acceptance in North America in applications where a very concentrated cake is required.

The design of a pressure filter depends upon determining the pressing time required to reach a specified cake solids concentration. Bench tests do not generally provide a sufficiently accurate estimate of this time requirement to be useful for design purposes. The operation of a pilot plant is recommended to provide reliable estimates.

Most bench scale filter presses have only one filtering surface such that when sludge is pumped into the chamber all of the liquid must flow in one direction. In full scale or pilot scale units the chambers have filter media on both sides. As filtration progresses the cakes formed at the two filtering surfaces build up to the point where they begin to interfere with each other, resulting in a decrease in the filtration rate. As filtration nears completion the bench test produces a significantly higher total filtrate volume per unit area than the pilot plant (Figure 9). Pressing times estimated on the basis of bench tests would tend to result in considerably lower cake solids than expected. The bench test is an excellent method of predicting the range of cake

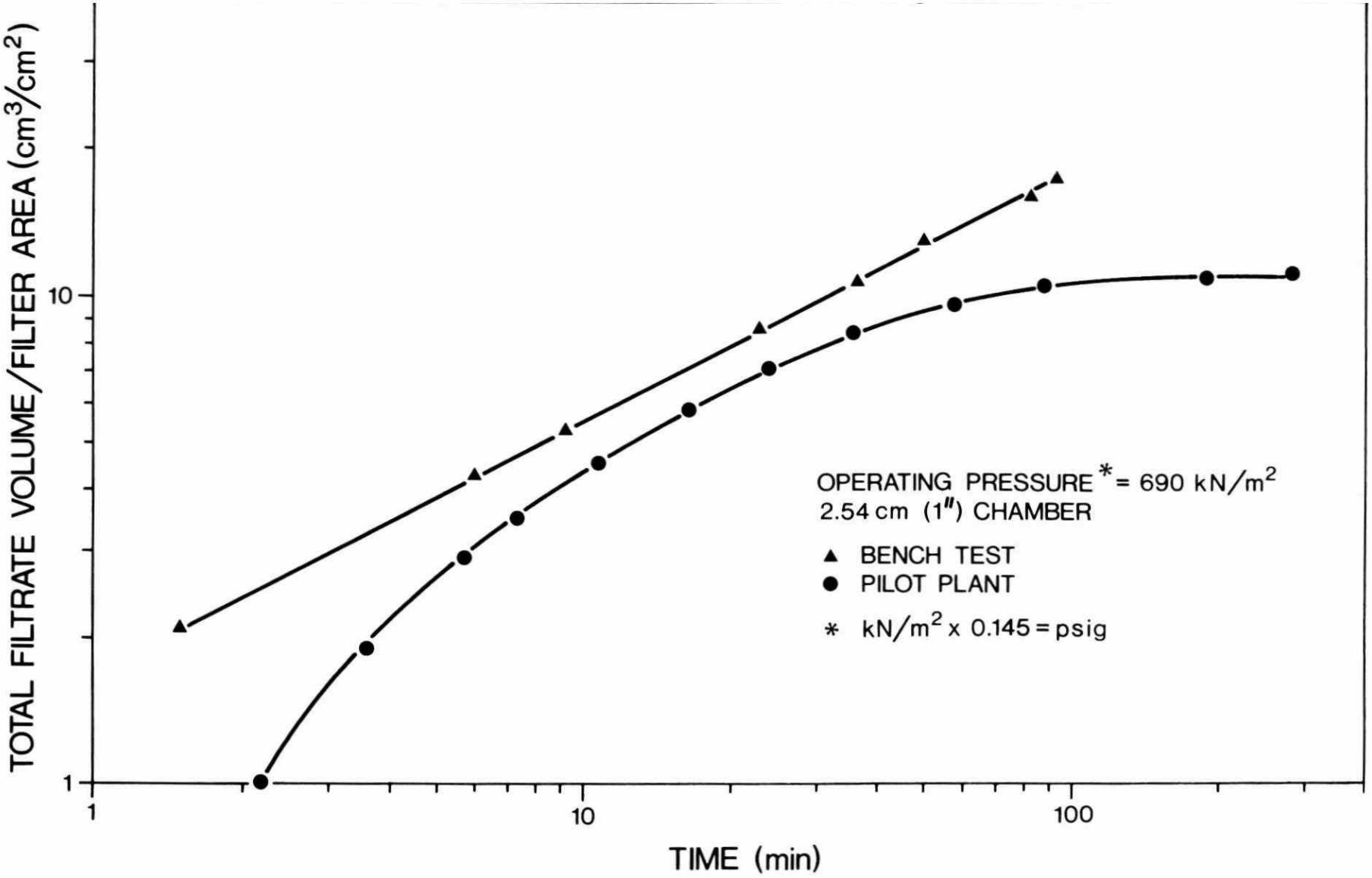

FIGURE 9. A COMPARISON OF BENCH AND PILOT SCALE PRESSURE FILTRATION OPERATION

solids and evaluating the effects of conditioners, filter media and operating pressure. Figure 10 illustrates how the test may be used to select the optimum polymer dosage. A polymer dosage of 2.125 kg/t resulted in the largest volume of filtrate in the shortest time. As the dosage was increased to 2.25 kg/t, the filtration rate decreased.

The design of full scale equipment based on pilot plant test data is illustrated by the following example:

SLUDGE CHARACTERISTICS

1. High lime sludge (base metal mine treatment waste)
2. Flow rate = 25 m^3/h (90 Igpm)
3. Feed solids concentration = 7%
4. Bulk density = 1.004 g/cm^3
5. Dry solids density = 3.256 g/cm^3

PERFORMANCE CRITERIA

1. Cake solids = 38%
2. Solids recovery $\geq$ 99%

A 45.7 x 47.7 cm (18 x 18 in) plate and frame pressure filter was operated using 4 chambers, to produce the results shown in Figure 11. A cotton filter media was used, but information on the porosity of the cloth was not available. Chemical conditioning was not required as all tests produced a filtrate with less than 10 mg/L of suspended solids.

In Figure 11, the filtration rate (L/min) at any time is given by the slope of the curves shown. For the 2.54 cm frames, the test conducted at a pressure of 690 kN/m^2 resulted in the highest filtration rate throughout the test. The end conditions of this test were as follows:

Press time = 464 min
Cake solids = 42.4%
Total filtrate volume = 163 L

Assuming the filtrate solids are negligible, the cake solids at any time (t_1) can be related to the cake solids at any other

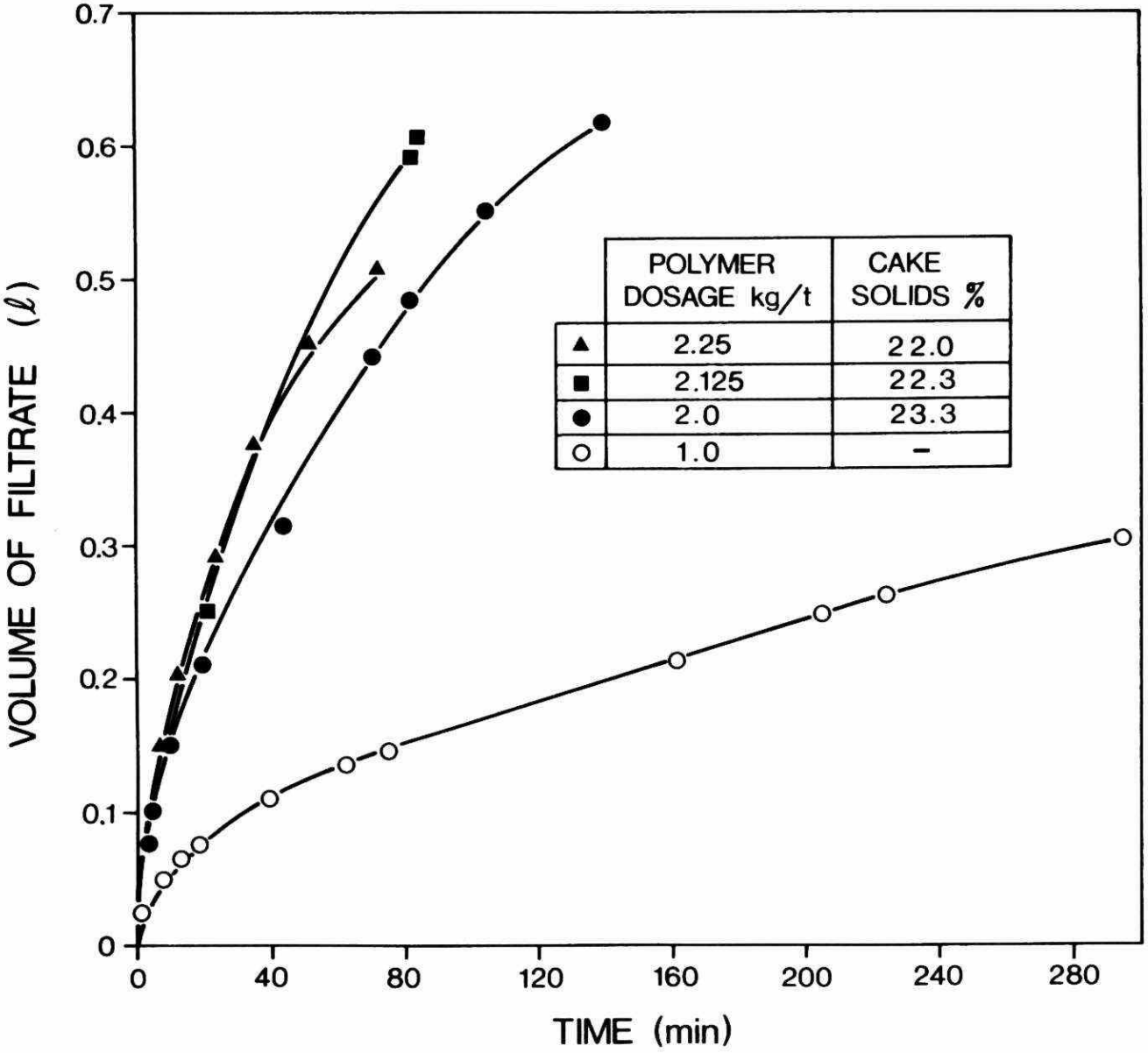

FIGURE 10. BENCH FILTER PRESS-COMPARISON OF CONDITIONING REQUIREMENTS

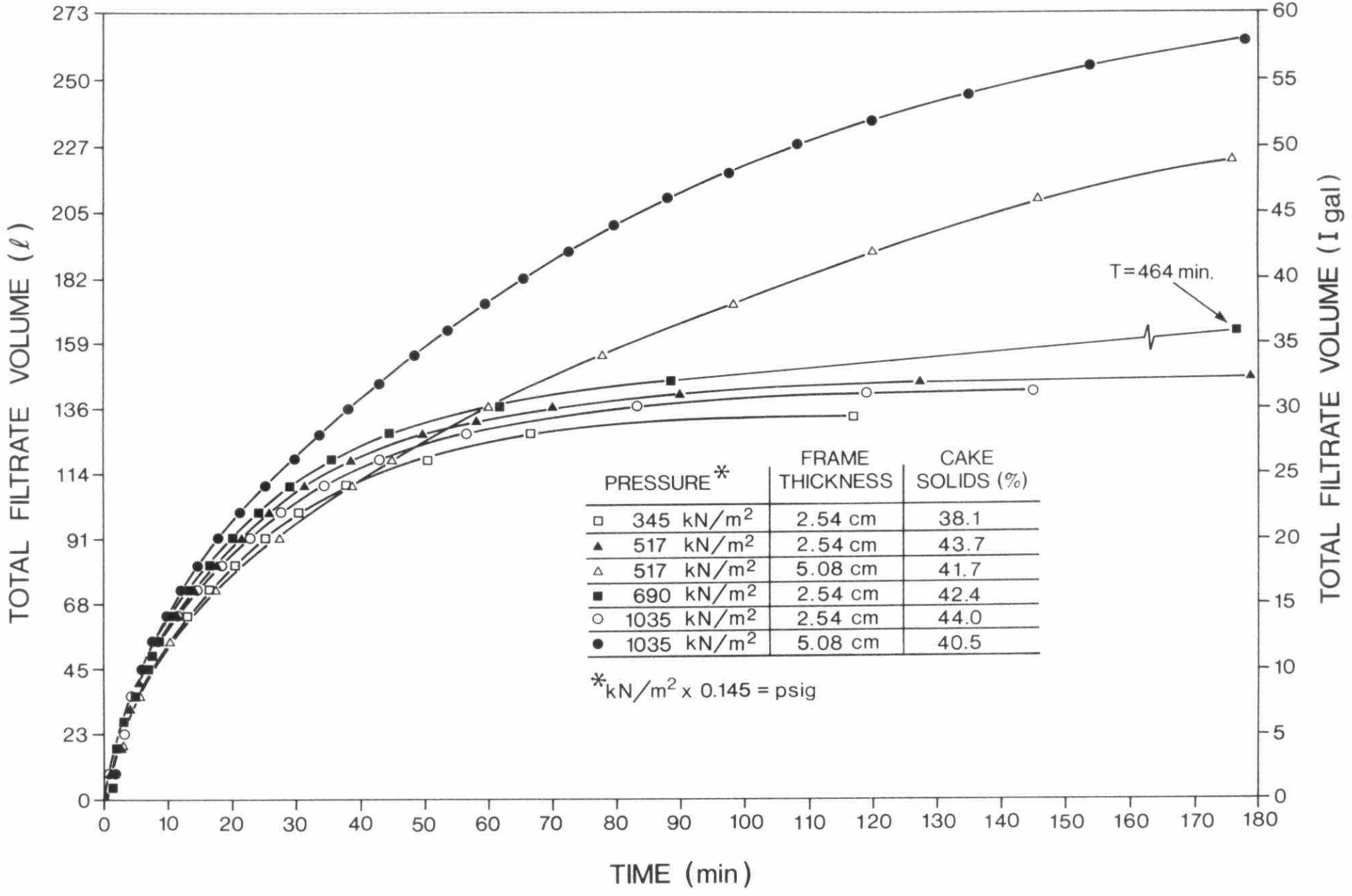
TOTAL FILTRATE VOLUME (ℓ)
TOTAL FILTRATE VOLUME (I gal)
TIME (min)
T=464 min.
PRESSURE*
FRAME THICKNESS
CAKE SOLIDS (%)
□ 345 kN/m² 2.54 cm 38.1
▲ 517 kN/m² 2.54 cm 43.7
△ 517 kN/m² 5.08 cm 41.7
■ 690 kN/m² 2.54 cm 42.4
○ 1035 kN/m² 2.54 cm 44.0
● 1035 kN/m² 5.08 cm 40.5
*kN/m² x 0.145 = psig

FIGURE 11. EFFECT OF OPERATING PRESSURE AND FRAME SIZE ON FILTRATE FLOW OF FILTER PRESS

time (t_2) by considering a mass balance according to the following relationship:

$$\left[\frac{C}{V_s}\right]_{t_2} = \left[\frac{C}{V_s}\right]_{t_2} \quad (9)$$

where: C = cake solids (%)

V_s = volume of sludge pressed (L)

The volume of sludge pressed is determined by:

$$V_s = V_f + V_c \quad (10)$$

where: V_f = volume of filtrate (L)

V_c = volume of chamber (L)

The chamber volume (V_c) for the pilot plant using 2.54 cm frames (chambers) was 17.9 L.

To obtain a cake solids of 38%:

C_2 = 42.4%

Vs_2 = 163 + 17.9 = 180.9 L (from Equation 10)

C_1 = 38%

Substituting into Equation 9:

$$V_{s1} = \frac{38 \times 180.9}{42.4} = 162.1 \text{ L}$$

According to Equation 10:

V_f = 162.1 - 17.9 = 144.2 L

Reference to Figure 11 indicates that at 690 kN/m^2 and 2.54 cm frames, 144.2 L of filtrate were collected in 90 min. Based on the assumption that 30 min of downtime are required at the end of each cycle:

total cycle time = 90 + 30 = 120 min (2 h)

Number of cycles/day = $\frac{24 \text{ h/d}}{2 \text{ h/cycle}}$ = 12 cycles/day

By considering the dry solids density (3.256 g/cm^3) it can be shown (Campbell et al, 1978) that a cake with 38% solids will have a density of 1357 kg/m^3.

$$\text{Dry solids flow rate} = \frac{25\ m^3}{h} \times \frac{24\ h}{d} \times \frac{1044\ kg}{m^3} \times \frac{.07\ kg}{kg}$$

$$= 43848\ kg\ dry\ solids/d$$

The volume of dewatered cake is:

$$\frac{43848\ kg/d}{1357\ kg/m^3} = 32.3\ m^3/d$$

The required press volume is:

$$\frac{32.3\ m^3/d}{12\ cycles/d} = 2.7\ m^3/cycle$$

Any combination of chamber size (area) and number of chambers which will provide a total volume of 2.7 m^3 (95.3 ft^3) in 2.54 cm chambers would be acceptable. A similar analysis of the test at 1035 kN/m^2 using 5.08 cm frames showed that a pressing time of 135 min was required to produce a cake solids of 38% (Campbell et al, 1978). This would result in a required press volume of 3.7 m^3 (130.6 ft^3). Based only on consideration of the size of equipment required, a press with 2.54 frames would be selected.

DESIGN SUMMARY

Flow Rate	25 m^3/h (90 Igpm)
Feed Solids Concentration	7%
Solids Flow Rate	43848 kg/d (96464 lbs/d)
Filter Press Volume	2.7 m^3 (95.3 ft^3)
Operating Pressure	690 kN/m^2 (100 psig)
Chamber Thickness	2.54 cm (1.0 in)
Pressing Time	1.5 h
Total Cycle Time	2.0 h
Chemical Conditioning	None
Cake Solids	38%
Solids Recovery	99%

Belt Filter Press

In the past few years a variety of new or modified sludge dewatering processes have become available which offer an alternative to conventional methods such as vacuum filtration and centrifugation. The device which has probably attracted the most attention is the belt filter press. A wide variety of mechanical configurations are available from the different manufacturers but the principle on which they operate is common to all units. The sludge is introduced between two filter belts which move over a series of rollers. The pressure exerted by the belts on the sludge becomes progressively greater as the belts move through the press. At the end of the press the two belts separate and the cake is discharged.

Very little information is reported in the literature on the methodology used to determine full scale requirements. Most manufacturers' brochures express the capacity of their belt filter presses in terms of either total volume of sludge throughput or weight of dry solids throughput.

Bench tests are not available for the generation of design data. At least one manufacturer has reported using a hand squeezing test. This permits a qualitative evaluation of whether it will tend to extrude through the filter media under application of pressure by the belts.

The pilot scale machines used to test a sludge are usually the smallest full scale machine made by the manufacturer. Pilot scale and full scale units are identical with the exception of belt width which may range from 0.5 to 3.0 m. Experience has shown that scale-up is not linear with respect to belt width because as the width increases the edge effect or amount of unused belt area becomes a progressively smaller proportion of the total surface area. At the present time the only way to determine full scale size requirements is to have a pilot plant machine tested on site. Based on the performance achieved by the small machine, recommendations as to expected full-scale performance and total equipment requirements can then be made.

COST ANALYSIS

The final step in the design procedure is the development of a cost estimate for each dewatering alternative. While it is always desirable to minimize costs, this must be done within the constraints imposed by the other design objectives. Preliminary cost estimates prepared under these constraints will determine which dewatering alternatives are economically feasible. The techniques available for cost estimation and the degree of confidence associated with each technique will be presented by a later speaker (Woods et al, 1978).

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NET ENERGY REQUIREMENTS FOR SEWAGE SLUDGE INCINERATION

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and
B. Wasmund
Hatch and Associates

INTRODUCTION

In the treatment of wastes at a sewage treatment plant following the various treatment processes, sludge solids still remain for disposal. More stringent laws and codes have reduced freedom of choice in disposing of such sludge solids.

Incineration of sludge solids is reaching new high levels of technology than generally realized. While sludge incineration has existed in Canada since 1954, new data recently developed answer favourably for the first time many questions that have surrounded the impact on air quality and energy requirements for such thermal processing systems. In addition, favourable benefits such as energy recovery from the burning of the sludge are becoming more widely accepted.

This paper will attempt to explore the various aspects of the thermal requirements and recovery of energy for sludge incineration to convey a better understanding of the process.

INCINERATION METHODS AND THERMAL REQUIREMENTS

The thermal energy required for incineration of sewage sludge is dependent primarily on four variables:

i) moisture content of sludge,
ii) percent excess combustion air used,
iii) incinerator off-gas temperature,
iv) temperature of combustion air supplied to the incinerator.

If the calorific value of the volatile matter in the sludge is not sufficient to supply the necessary thermal requirements, then auxiliary fuel is required to make up the deficiency.

The calorific value of the sludge (Btu/lb dry solids) depends on its content of volatile matter and can vary widely depending on the effluent source and treatment process used, as discussed later in the paper. Combustion of the sludge volatile matter is similar to that for hydrocarbon fuels and has a theoretical air requirement of about 1 scf per 1000 Btu of heat liberated. The fraction of the calorific heat available for evaporation and heating the moisture in the sludge is markedly effected by the excess air used, air pre-heat temperature and incinerator off-gas temperature. These factors can be assessed quantitatively with the aid of standard combustion graphs. A thermally efficient incinerator will exhibit:

- low excess air,
- low off-gas temperature,
- preheated combustion air.

In practice, the excess air level and incinerator off-gas temperatures must both be sufficiently high to ensure complete elimination of hydrocarbons, odours and organic compounds present in the sludge. The required levels vary with the type of incineration process used as discussed below. It should be noted that high off-gas temperature does not penalize overall thermal efficiency if heat is recovered from the incinerator off-gases.

A number of different types of incinerators are used for sludge incineration, including multiple hearth furnaces, fluid bed reactors, and recently, electrically heated travelling belt furnaces. Each of these methods is discussed below, with particular emphasis on the first two types, since they are in widespread use.

MULTIPLE HEARTH INCINERATORS

The earliest and most widely used incinerator for sewage sludge is the multiple hearth furnace, there being approximately 300 units currently in operation in North America. A typical incineration system is shown in Figure 1 and a section through the furnace is given in Figure 2.

Dewatered sludge is delivered to a cake hopper on top of the furnace by a belt conveyor and is charged through a counterweighted gate

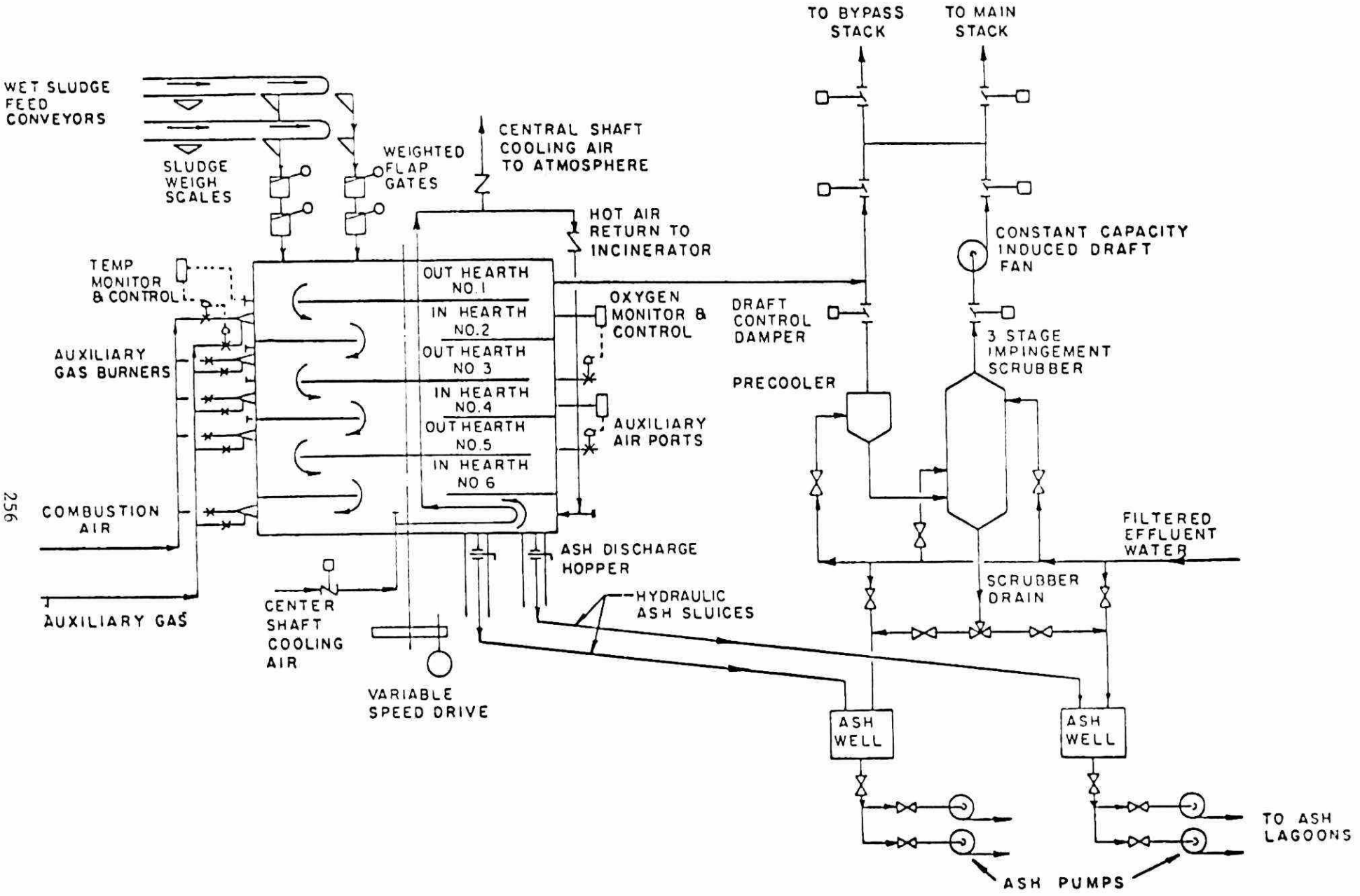

FIGURE 1. MULTIPLE HEARTH INCINERATION SYSTEM

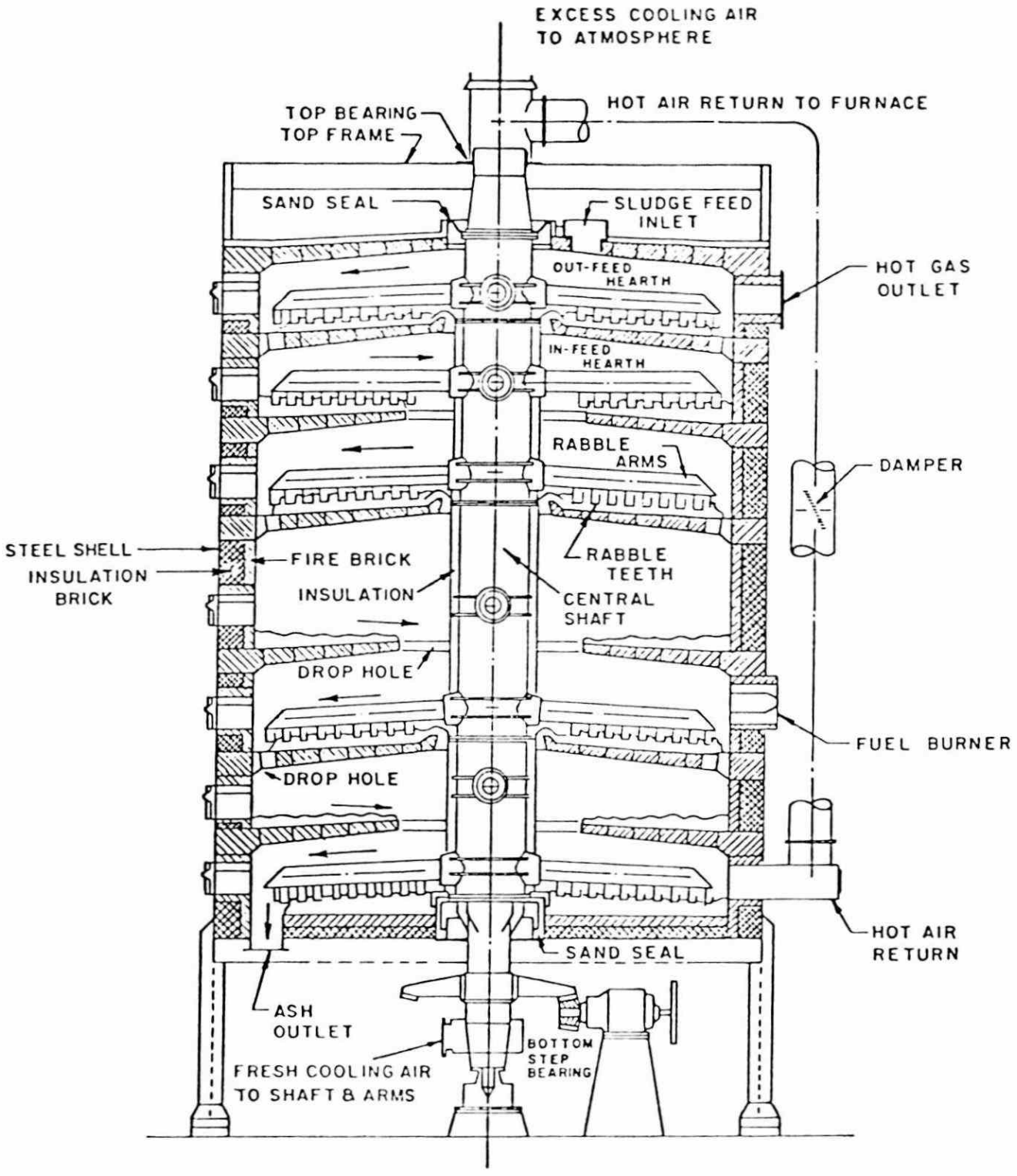

FIGURE 2. TYPICAL SECTION OF MULTIPLE HEARTH INCINERATOR

near the centre of the top hearth. The rotating rakes spread the cake into a thin bed which is continually raked towards the periphery of the top hearth where it is discharged through a drop hole onto the second hearth. On the second hearth, the sludge bed is raked towards the centre of the hearth and discharged through a drop hole onto the third hearth. In this manner, the rakes progressively transfer the sludge solids downwards across each hearth of the furnaces, as illustrated in Figure 1. Air and combustion gases are drawn upward over the hearths countercurrent to the solids flow. The wet sludge is dried and pre-heated in the top hearths by the hot combustion gases rising from the burning hearths in the middle of the unit. In the bottom hearths, part of the combustion air is preheated by direct contact with the descending sludge ash which is discharged from the bottom hearth of the furnace. The burning hearths are equipped with burner openings through which combustion air and auxiliary fuel are fired to maintain the desired temperature conditions.

Typical temperature distributions of the gases for each hearth of a large 12-hearth unit are given below.

Hearth No.	Temperature ^{o}F
No. 1 (top)	700 - 1100
2	900 - 1100
3	900 - 1200
4	1100 - 1400
5	1300 - 1600
6	1450 - 1600
7	1450 - 1600
8	1450 - 1600
9	700 - 900
10	300 - 700
11	300 - 600
12 (bottom)	300 - 400

Although gas-solids contact occurs only at the surface of the cake beds, the continuous mixing action of the rakes in combination with the large surface area provided by the multiple hearths makes the multiple hearth furnace a reasonably efficient contacting device. Since

the major portion of the moisture is eliminated in the drying hearths, the cake arrives on the burning hearths in a semi-dry condition. Consequently, the thermal demand on the burning hearths is considerably reduced and large volumes of excess air must be admitted over the burning hearths to avoid overheating and sintering of the cake ash. Typically, the furnace off-gases contain 100-200% air in excess of the stoichiometric requirements for burning the sludge and auxiliary fuel; the higher excess air requirements occur with decreased moisture content in the sludge feed.

Despite the high excess air requirement, multiple hearth furnaces have traditionally been a thermally efficient method of incinerating sewage sludge because the heat required for drying and heating the cake moisture is obtained by staged, countercurrent contact with the hot combustion gases which are simultaneously cooled in the process. The resulting low furnace off-gas temperatures, in the range of 500 - 800°F, not only provided high incinerator thermal efficiencies, but additionally reduced the cooling load in the off-gas scrubber circuit. However, since the promulgation of stricter air pollution regulations, higher off-gas temperatures must be maintained to ensure adequate elimination of hydro-carbons, odours and organic pollutants such as PCBs from the off-gases. Based on investigations conducted to date, indications are that a lower limit of at least 1100°F is necessary to meet current gaseous emission standards. The required increase in off-gas temperature coupled with the inherent high excess air volumes used, result in a substantial reduction in thermal efficiency in multiple hearth incinerators.

The calculated thermal requirements for multiple hearth incinerators operated with 100% excess air and 1100°F off-gas temperature are shown in Figure 3. In the Figure, auxiliary fuel required, expressed as Btu per pound of dry solids, is plotted versus percent dry solids in the feed cake for sludges with varying calorific values. For example, a sludge dewatered to 30% solids with a calorific value of 10,000 Btu/lb dry solids requires auxiliary fuel firing equivalent to 1,250 Btu/lb dry solids. The total thermal demand is therefore 11,250 Btu/lb dry solids. Figure 3 also shows that a sludge with a calorific value of 10,000 Btu/lb

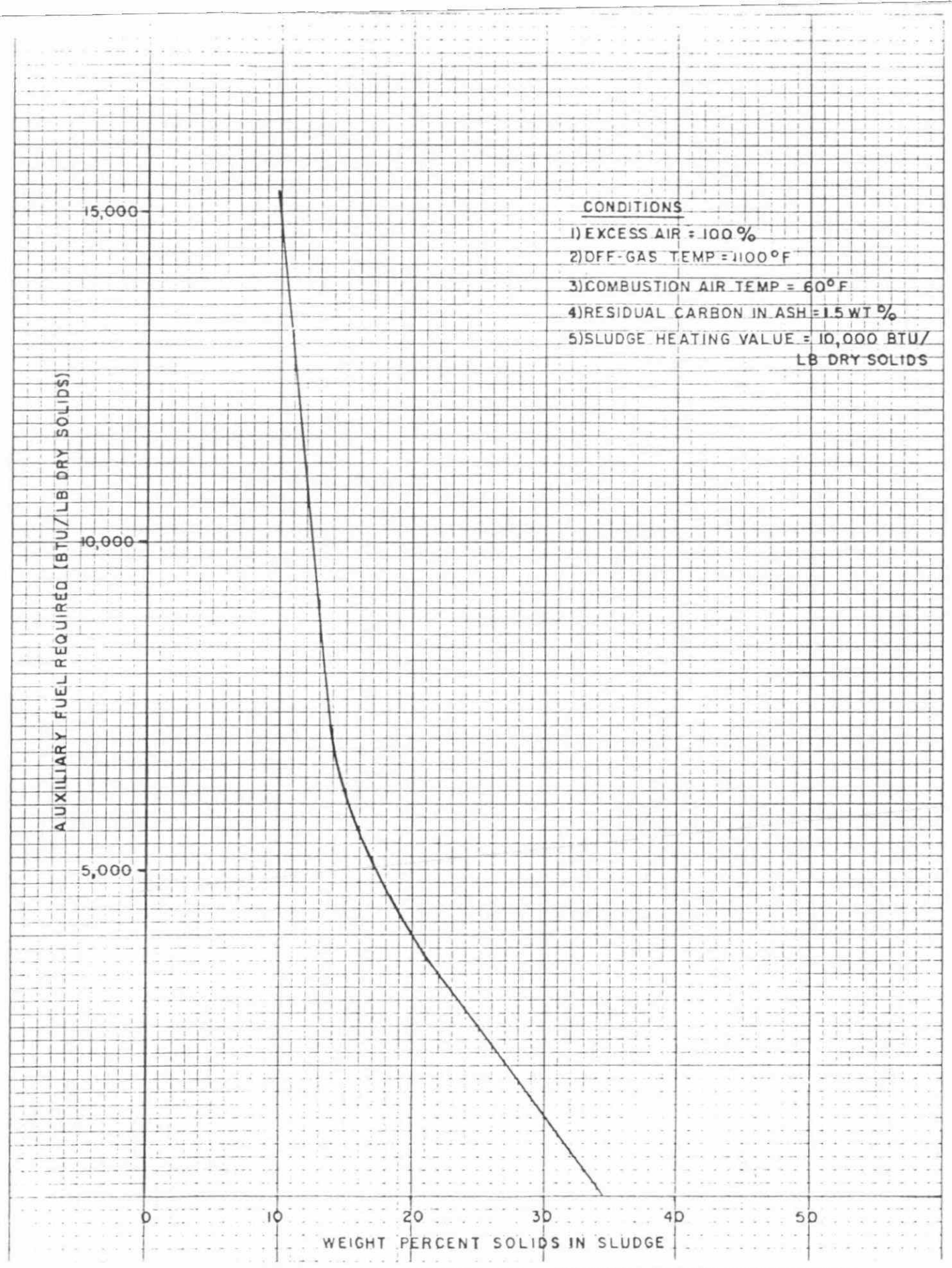

FIGURE 3. AUXILIARY FUEL REQUIREMENTS - MULTIPLE HEARTH INCINERATORS

dry solids must be dewatered to 34.5% solids to enable autogeneous operation of a multiple-hearth incinerator.

A multiple hearth incinerator is sized on the basis of a specific sludge loading rate on the burning hearths. Design values range from 7.5 to 9.5 lb sludge per hour per square foot, the value decreasing with increasing cake moisture. The largest units presently available have 12 hearths and are about 25 feet O.D. This unit can treat about 40,000 lb/hr of wet sludge containing 20% solids, which is equivalent to a heat release rate of 80 x 10^6 Btu/hr. The smallest practical size is about 6 feet O.D. and has 6-7 hearths. This unit would treat about 400 lb/hr of sludge cake.

FLUID BED INCINERATORS

Fluid bed reactors have been adapted for sewage sludges incineration during the past twenty years and there are currently about 120 of these units in operation in North America. A typical fluid bed incinerator is shown in Figure 4 and a single "cold windbox" system is shown in Figure 5.

Combustion air supplied from a blower at a pressure of about 4 to 4.5 psig enters the bottom section of the reactor called the "windbox". Air passes from the windbox into the fluidized bed through a large number of tuyeres fitted into the constriction plate which separates the two sections. The tuyeres are designed to provide sufficient pressure drop, normally 15 to 20" w.c., to ensure uniform air distribution across the entire bed and to prevent sifting of the bed sand into the windbox.

Combustion is carried out in a fluidized bed of inert silica sand about 5 feet deep which is maintained in the range of 1350 - 1400°F. The sludge cake is fed into or onto the fluidized sand bed and is rapidly mixed into the bed where the water is evaporated and the volatiles are combusted by the oxygen in the fluidizing air. Due to the turbulent mixing of the solids, the temperature is uniform throughout the bed, not varying by more than $\pm$10°F.

The combustion gases and water vapor leaving the top of the fluidized bed carry out the ash residue from the sludge along with some bed sand. Most of the entrained sand is disengaged in the reactor

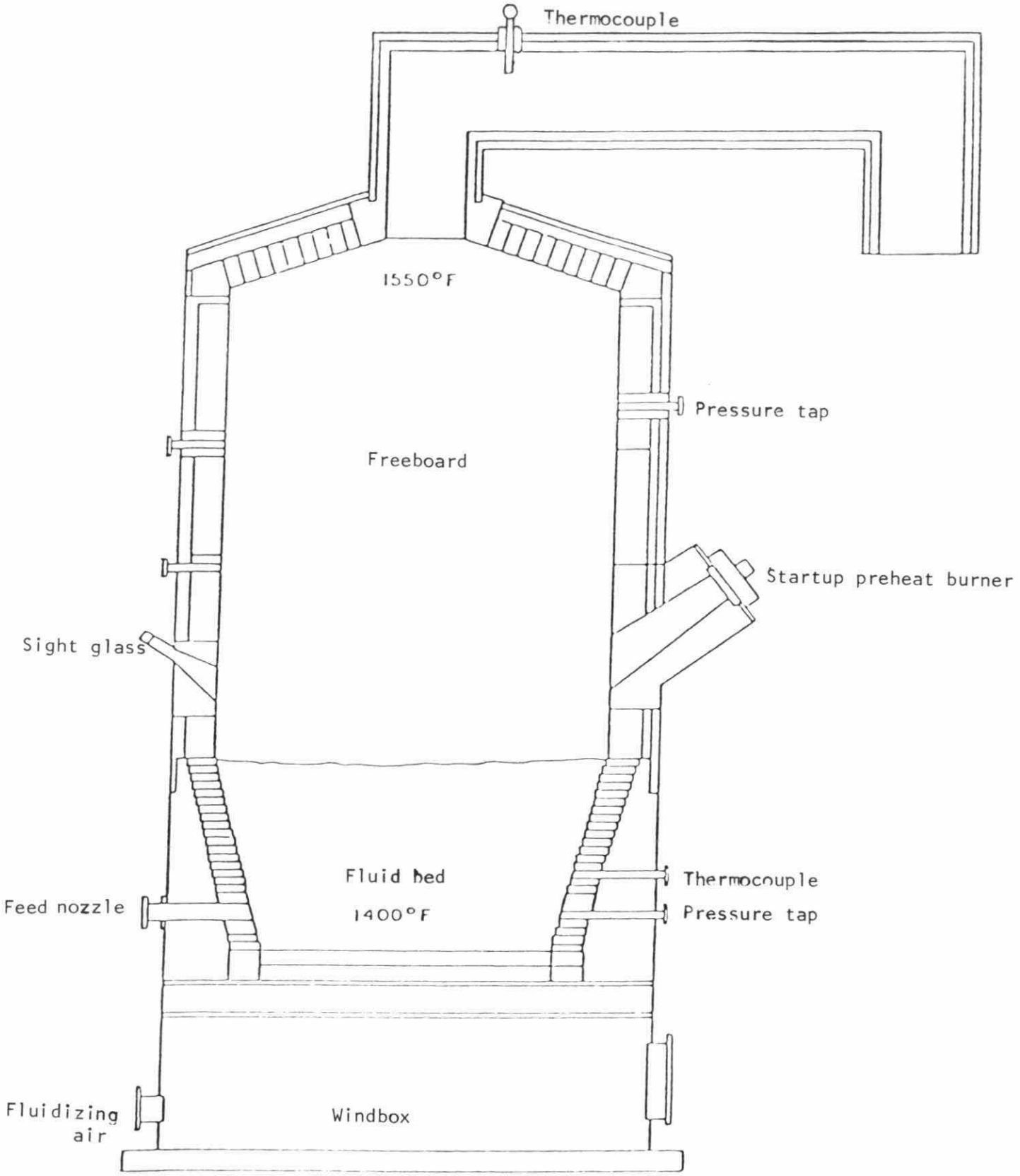

FIGURE 4. COLD WINDBOX FLUID BED REACTOR

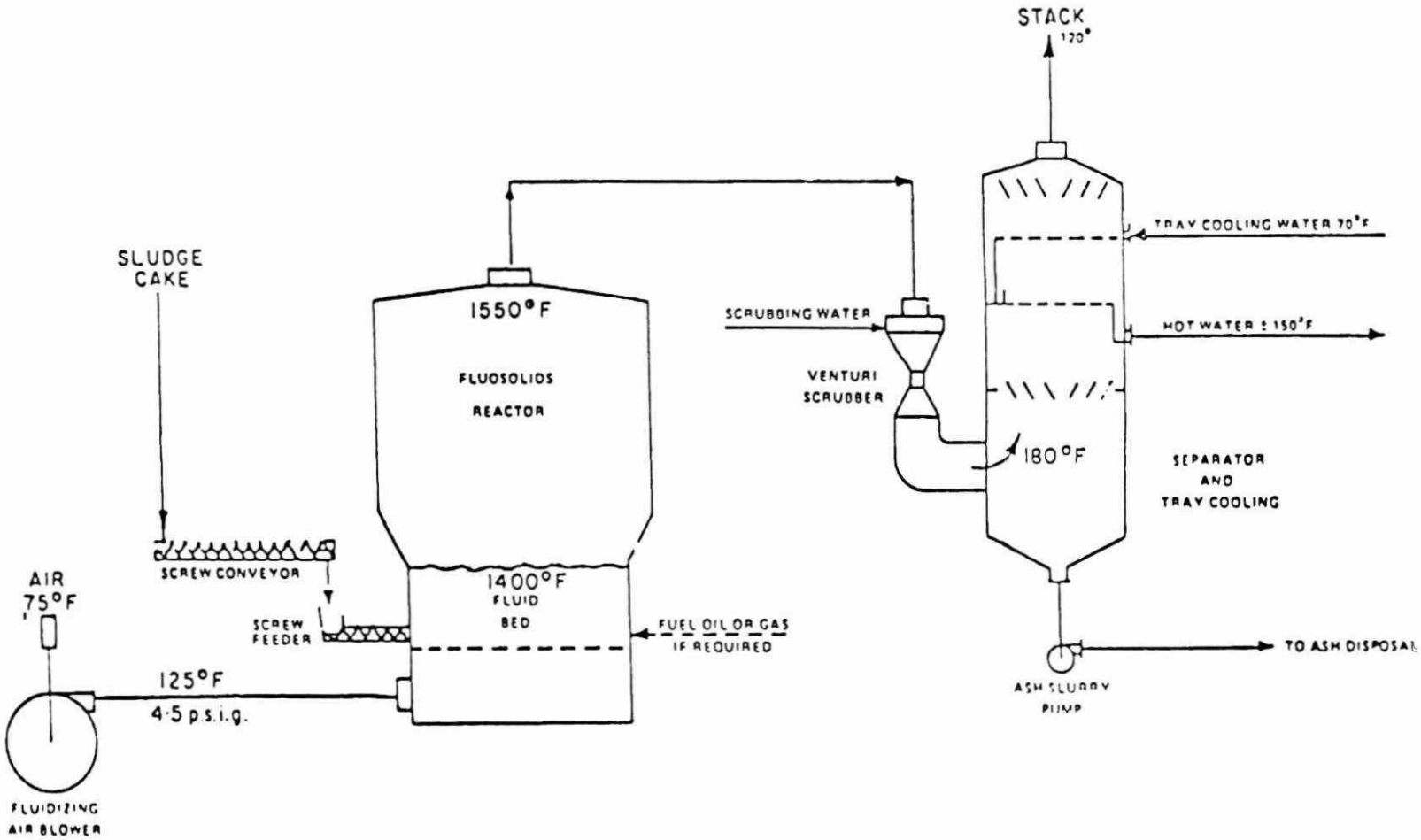

FIGURE 5. COLD WINDBOX FLUID BED INCINERATOR

freeboard and falls back into the bed, while the ash and a small amount of the finer sand particles are carried out of the reactor with the off-gas. A fraction of the sludge volatiles are also carried into the freeboard where they burn and raise the gas temperature to 1500 - 1550°F.

Due to the excellent gas-solids contacting and uniformly high temperature recurring in fluid bed incinerators, excess air levels of 20-35% are sufficient to ensure adequate elimination of hydrocarbons, odours and organics from the sludge. Actual excess air requirements decrease with increasing off-gas temperature, e.g. 35% excess air is used at 1500-1550°F, while 20% excess air is adequate at temperatures about 1600°F. Because of the low excess air requirement, fluid bed reactors are thermally efficient incinerators, despite the high off-gas temperatures. Furthermore, high off-gas temperatures permit efficient heat recovery from the off-gases and this feature has been exploited in the "hot windbox" design shown in Figure 6. In this system, a gas-air heat exchanger installed in the off-gas flue is used to pre-heat the reactor combustion air to about 1000°F. There are currently about 40 hot windbox sewage sludge incinerators in operation and the technology is well proven.

Computed thermal requirements for a simple cold windbox incinerator operated with 35% excess air and 1550°F off-gas temperature are given in Figure 7. The figure shows that an incinerator burning sludge containing 30% solids with a calorific value of 6000 Btu/lb dry solids will require auxiliary fuel firing equivalent to 9200 Btu/lb dry solids. The figure also shows that a sludge with 6000 Btu/lb dry solids calorific value would have to be dewatered to a solids content just over 41% for autogeneous operation in a cold windbox reactor.

Figure 8 is a similar graph showing the thermal requirements for a hot windbox incinerator. In this design the auxiliary fuel required for a sludge containing 30% solids with a calorific value of 6000 Btu/lb dry solids is only 350 Btu/lb dry solids, thus reducing the total thermal demand to 6350 Btu/lb dry solids. This represents an energy savings of 31% over the cold windbox design. Furthermore, a sludge with a calorific value of 6000 Btu/lb dry solids need only be dewatered to about 31% solids for

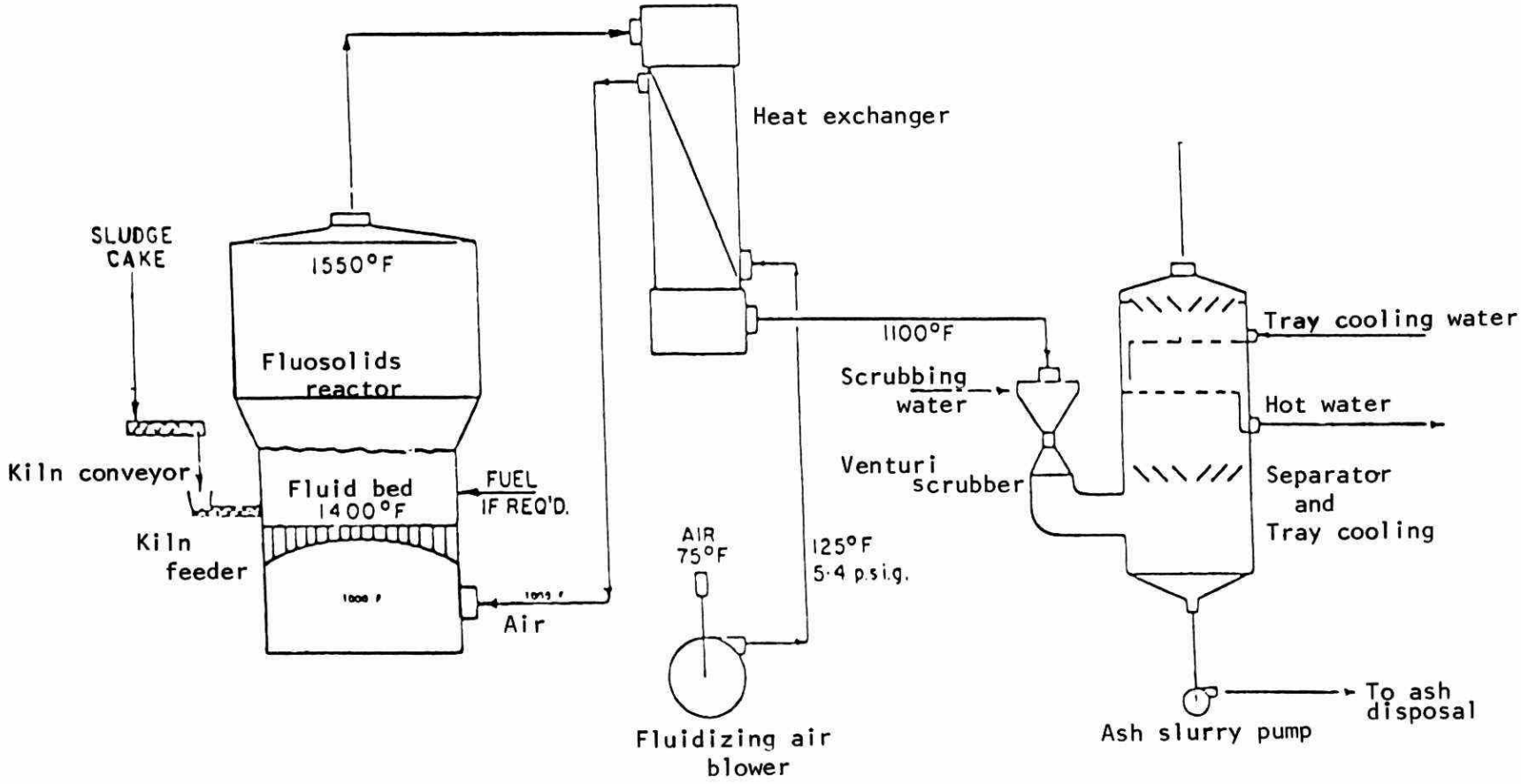

FIGURE 6. HOT WINDBOX FLUID BED INCINERATOR

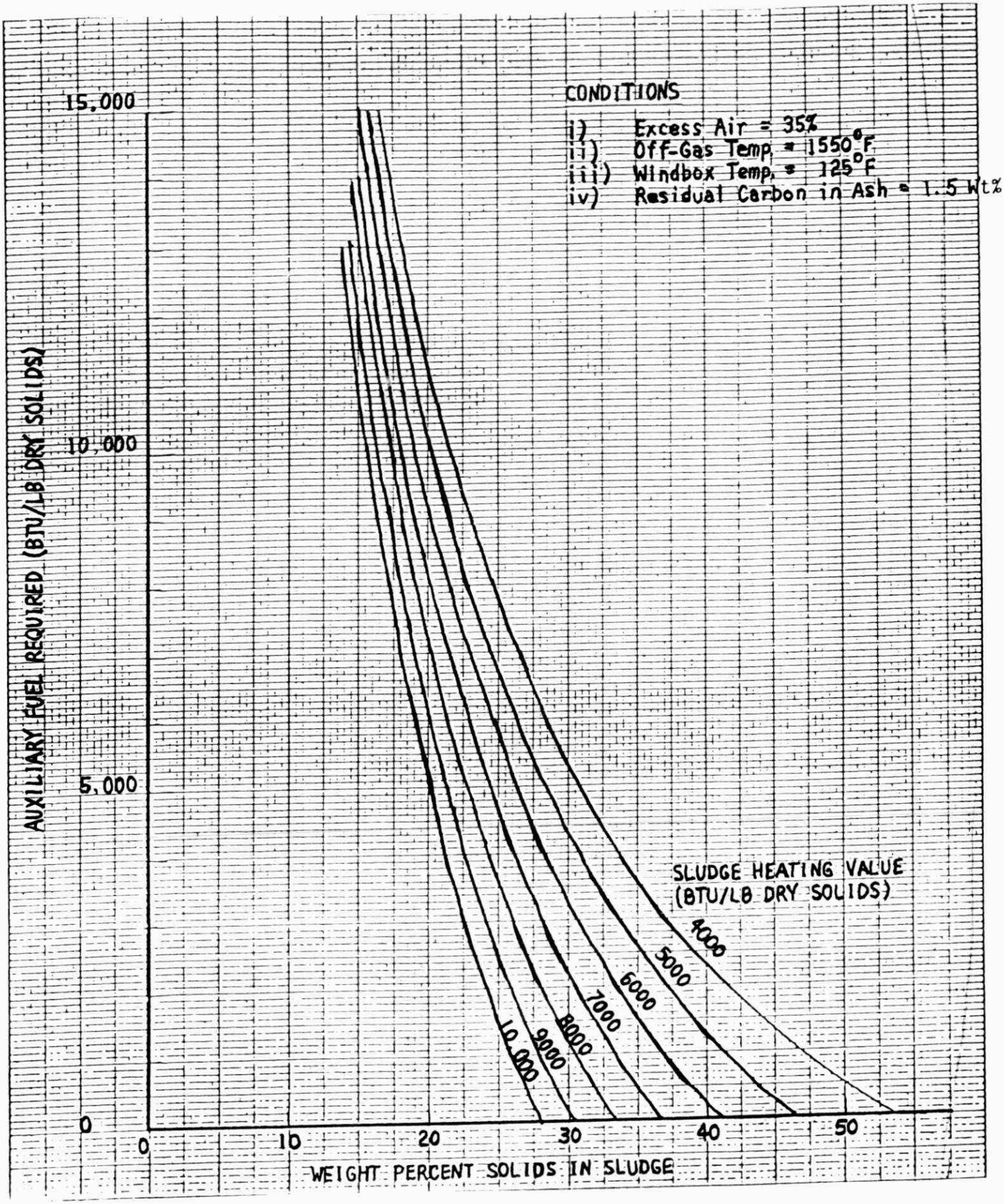

FIGURE 7. AUXILIARY FUEL REQUIREMENT IN COLD WIND-BOX INCINERATOR

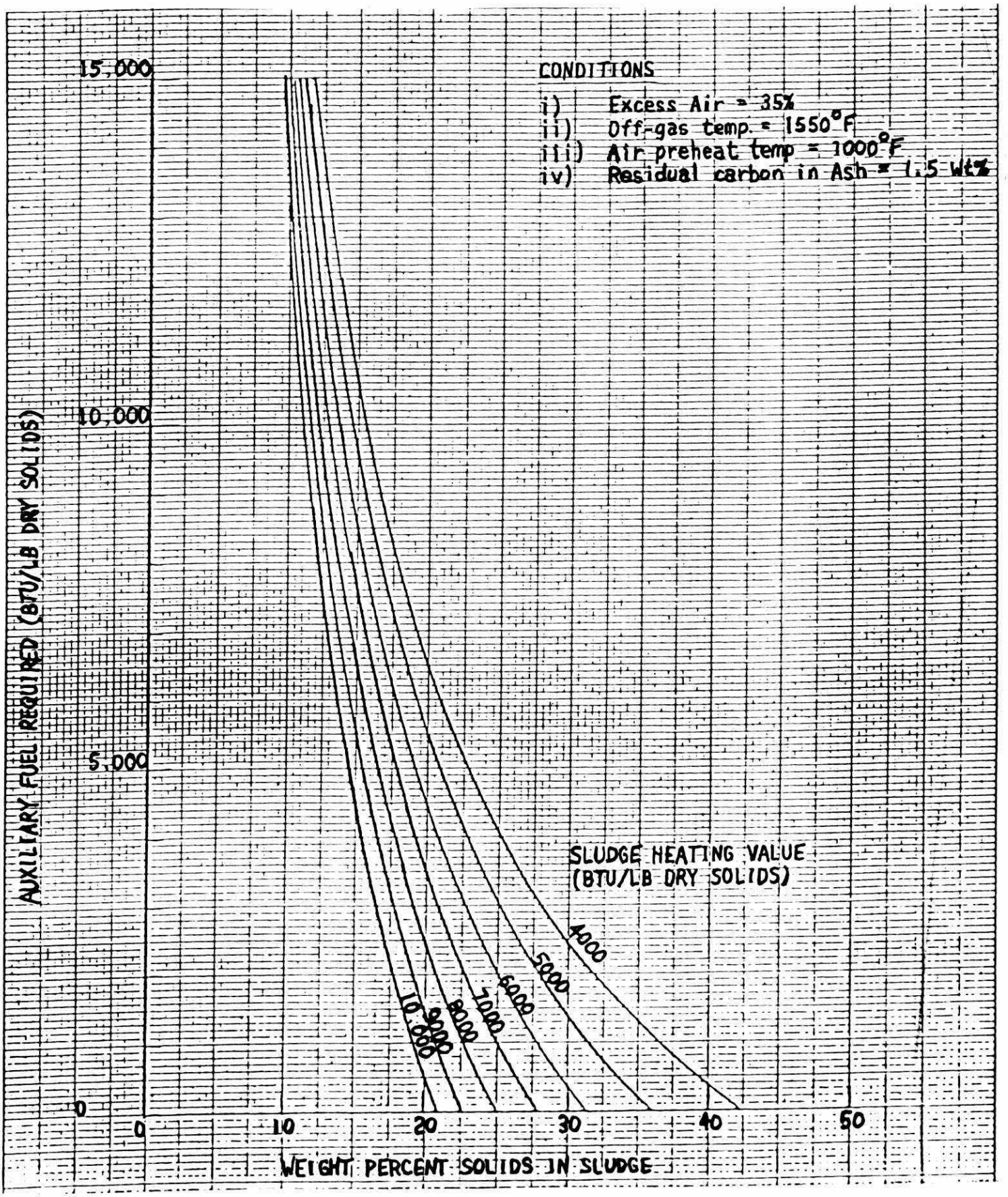

FIGURE 8. AUXILIARY FUEL REQUIREMENT IN HOT WIND-BOX INCINERATOR

for autogeneous incineration in a hot windbox reactor. Also, since the air rate and reactor diameter are directly related to the total energy released, the hot windbox design provides (9200-6350)/6350 or 45% more throughput for a given reactor size.

The physical size of a fluid bed incinerator is determined by the sludge throughput rate required, the total thermal demand of the particular sludge and the air velocity used at the bottom of the bed. The air velocity is dictated in part by the size of sand used to form the bed, but more importantly, by the residence time required for the combustion reactions. Current designs use a space velocity of about 2.5 ft/sec, which provides two seconds gas retention time in a 5 ft deep bed. A further three to five seconds residence time is provided in the freeboard volume above the bed.

Assuming the following conditons:

i) stoichiometric air required = 1 scf/100 Btu (gross) liberated,

ii) excess air used = 35%,

iii) temperature and pressure of 1400°F and 3 psig at bottom of bed,

iv) air velocity of 2.5 ft/sec at the bottom of the bed,

it can be readily shown that the reactor size is given by:

$$D = 2.38 \times \sqrt{Q} \text{ feet I.D. at hearth,}$$

where: Q is the total heat released in million Btu/lb.

The largest size of cold windbox reactor is limited by the structural design of the self-supporting roof refractory, which is limited to about 45 feet. The corresponding hearth I.D. is about 35 feet, and this reactor would provide a total heat release rate of about 215×10^6 Btu/hr.

The largest size of hot windbox reactor is limited by the structural design of the refractory hearth dome, which is about 22 feet in current designs. This size will provide a total heat release rate of about 85×10^6 Btu/hr. It should be pointed out that hot windbox reactors utilizing stainless constriction plates can be built larger than 22 feet I.D. and that larger refractory hearth designs are also underway.

Fluid bed incinerators can be built as small as desired. Units as small as 4 feet I.D. have been used on a production basis. The thermal efficiency is not significantly reduced by decreasing the reactor size.

The method of feeding sewage sludge into a fluid bed incinerator is dependent on the physical characteristics of the sludge, particularly the water content. Sludges dewatered to less than 20% solids can readily be pumped through simple feed guns directly into the bed by means of Moyno pumps. Above 20% solids, screw feeders are commonly used. For sludge cakes with 30-35% or higher, which are light enough for air conveying, pneumatic injection is a practical feeding method. Pumpable sludges can also be injected as a coarse spray through an air assisted nozzle located in the reactor roof. The feeding method should be thoroughly evaluated for each particular sludge.

Virtually all types of fuel can be used for auxiliary firing a fluid bed incinerator. Oil is the simplest fuel to use as it is readily absorbed on the bed sand and burns uniformly throughout the bed. Natural gas or digester gas can also be used, in which case the gas is either fired into the bottom of the bed or into a refractory-lined hot windbox. More recently, coal-burning fluid bed reactors have been developed and this technology is readily applicable to sludge burning. Auxiliary firing is controlled easily and accurately, either manually or automatically, by monitoring the bed thermocouples.

A foundry grade silica sand sized at minus 10 mesh is the preferred unit bed material. However, local pit sand can often be used, the key requirements being resistance to thermal shock and absence of clay constituents which could form low melting point phases in the bed. A small amount of bed sand is continuously used up due to decrepitation and carry-over, the amount generally less than 3% of the bed-inventory per day. Normally, fresh sand is added about once per week.

Operationally, the fluid bed reactor is a very stable and readily controlled method of incineration by virtue of the uniform temperatures throughout the system and because of the large thermal inertia contained in the bed sand. The latter effect provides ample response time for correcting changes in sludge moisture, feed interruptions, etc. The

reactor can be shut down readily, and will retain sufficent heat in the bed sand over a 24-hour shutdown to enable re-starting without a lengthy preheating period.

HEAT RECOVERY FROM INCINERATOR OFF-GASES

Gas-Air Heat Exchangers

As mentioned previously, gas-air heat exchangers are used in the "hot windbox" fluid bed incinerator for preheating the combustion air. Shell and tube heat exchangers are used, and the exchanger is normally mounted vertically with the hot reactor gases entering the top and passing down through the tubes, as shown in Figure 6. Fluidizing air from the blower passes counter-currently in a single pass through a shell side and exits the top at about 1000°F. Typically, two-inch stainless steel tubes are used and a bellows expansion joint is provided on the bottom of the sheet. The heat exchangers are gas-tight and the entire gas train is forced drafted from the fluidizing blower. There are a number of competent heat exchanger manufacturers.

To the author's knowledge, there are no multiple hearth furnaces equipped with gas-air heat exchangers, nor would there appear to be any incentive for installing them since excess cooling air is required for temperature control on the burning hearths.

Waste Heat Boilers

At the present time, there is very limited experience with waste heat boilers on sewage sludge incinerators. There are about four multiple hearth incinerators equipped with boilers and three fluid bed units in a West Berlin plant. Although "teething" problems have been experienced in some of these installations, the practice of recovering waste heat system from dirty off-gases has been used for years in the chemical and metallurgical industries and this technology is readily available. Many of the new incinerator installations are incorporating waste heat boilers.

The flow sheet for a waste heat boiler installation on a cold windbox fluid bed incinerator is shown in Figure 9. A natural circulation boiler equipped with soot blowers for cleaning the tubes is

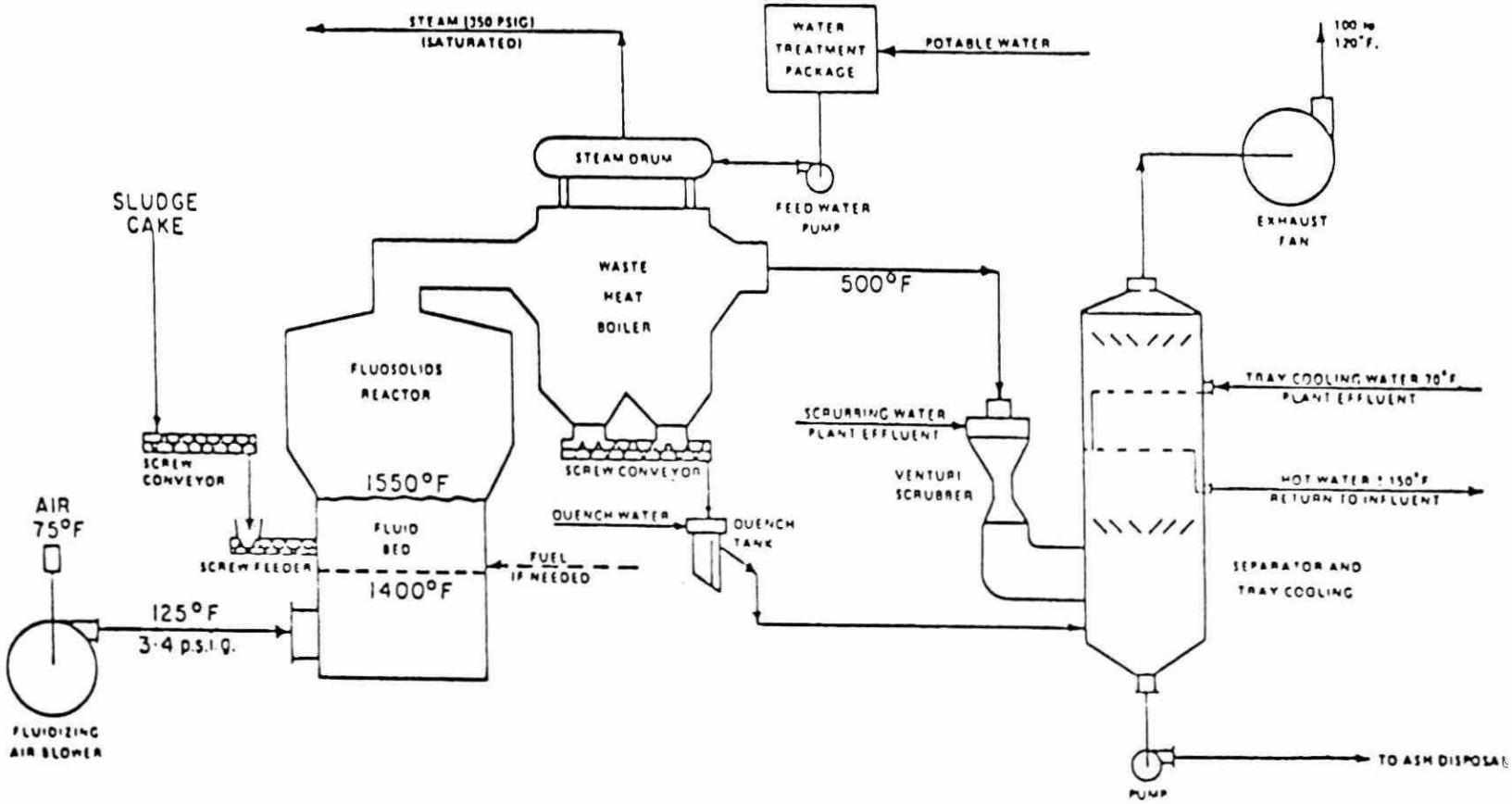

FIGURE 9. COLD WINDBOX REACTOR WITH WASTE HEAT BOILER

required. The boiler should be provided with a dust hopper and screw conveyor for removing dust which settles out. The use of an induced draft fan after the scrubber is desirable with a boiler installation in order to maintain a slight draft in the boiler and thereby prevent gas and dust leakage into the building.

The boiler can be equipped with a superheater tube section if it is desired to use the steam in a power turbine. Otherwise, it is preferable to make saturated steam. For economical boiler sizing, the outlet gas temperature should be at least 100°F above the saturated steam temperature. Another important factor is to keep the saturation steam temperature well above the H_2SO_4 dewpoint of the off-gases in order to avoid tube corrosion in the last tube banks. Normally, the saturated steam temperature should be kept above 400°F, which requires 235 psig steam pressure. The off-gas temperature would therefore be limited to a minimum of 500°F.

If the steam demand is erratic, then the use of a hot gas by-pass duct to the scrubber inlet is desirable. Otherwise, a condenser will be required during periods of low steam demand.

Because of the high off-gas temperatures available from a fluid bed incinerator, it is often feasible to use both a gas-air heat exchanger and a waste heat boiler to obtain maximum heat recovery. Where maximum air pre-heat is required, the gas-air heat exchanger will precede the boiler. In this case, the off-gas temperature at the boiler inlet will be about 1100°F. If the sludge burning is closer to autogeneous and full air pre-heat is not required, the boiler is placed ahead of the heat exchanger to maximize steam recovery.

EFFECT OF WASTE HEAT RECOVERY ON INCINERATOR ENERGY REMOVAL

The quantity of waste heat system produced varies directly with the flow rate of incinerator off-gases and the gas temperature drop across the boiler. Therefore, the percent heat recovery obtainable increases substantially with gas temperatures providing higher heat transfer rates per unit of boiler tube area, which reduces the boiler cost per unit of steam production. Thus a waste heat boiler installed on a fluid bed incinerator exhausting at 1550°F is thermally more efficient and

more economical than on a multiple hearth furnace exhausting at 1100°F. This fact is clearly demonstrated in Table 1, which presents a comparison of the incinerator fuel requirements (sludge plus fuel) potential heat recoveries and net thermal demands for multiple hearth and fluid bed incinerators both burning the same sludge at the same rate. The table yields the following conclusions:

1. A multiple hearth furnace operated with 100% excess air and 1100°F off-gas temperature requires less auxiliary fuel than a simple cold windbox fluid bed; auxiliary fuel required is 48.2 x 10^6 Btu/hr for multiple hearth versus 54.3 x 10^6 Btu/hr for cold windbox fluid bed.
2. Waste heat steam recovery is higher in the cold windbox fluid bed than in the multiple hearth furnace; 31.5 x 10^6 Btu/hr versus 20.4 x 10^6 Btu/hr.
3. Net energy demand, defined as auxiliary fuel less waste heat steam credit, is less for the cold windbox fluid bed than for the multiple hearth; 22.9 x 10^6 Btu/hr versus 27.9 x 10^6 Btu/hr.
4. The hot windbox fluid bed incinerator requires considerably less auxiliary fuel than the multiple hearth furnace, only 32.8 x 10^6 Btu/hr. It also has the least net energy demand if equipped with a waste heat boiler; 18.6 x 10^6 Btu/hr.

Similar incineration energy balances to those given in Table 1 were prepared for sludges obtained from six different pretreatment and dewatering methods. The moisture content and sludge calorific values varied widely for the different sludges such that some required auxiliary fuel for incineration (e.g. sludge in Table 1), whereas others were super-autogeneous, i.e. no auxiliary fuel required for incineration. The results yielded two general conclusions:

1. For sub-autogeneous sludges, hot windbox fluid bed incinerators required the least auxiliary fuel and provided the lowest net energy method of incineration.
2. For super-autogeneous sludges, i.e. no auxiliary fuel required for incineration, cold windbox fluid bed incinerators

TABLE 1. COMPARISON OF ENERGY REQUIREMENTS IN MULTIPLE HEARTH AND FLUID BED INCINERATORS

Basis:
i) Sludge Moisture Content = 87%
ii) Sludge Calorific Value (Gross) = 5400 Btu/lb Dry Solids
iii) Incineration Rate - 2808 lb/hr Dry Solids (50 Imgd Sewage Treatment Plant)

	Multiple Hearth Furnace	Fluid Bed Reactor Cold Windbox	Fluid Bed Reactor Hot Windbox
1. Incinerator Conditions			
i) Off-gas temperature (^{o}F)	1100	1550	1550
ii) Percent Excess Air	100%	35%	35%
iii) Total Combustion Air (SCFM)	21,200	15,430	10,64
iv) Total Off-gas Volume (SCFM)	29,200	22,820	17,85
v) Incinerator Size	8 Hearths @ 22'-3"ID	20 ft. ID	16 Ft. ID
2. Incinerator Heat Balance (10^{6} BTU/hr)			
Heat Required			
i) Sensible & Latent Heat in Off-gas	62.76	68.44	57.91
ii) Sensible Heat in Sludge Ash	0.20	0.38	0.38
iii) Sensible Heat in Elutriated Bed Sand	-	0.04	0.03
iv) Surface Heat Losses	0.28	1.48	1.02
v) Centre Shaft Cooling	2.28	-	-
Total	65.52	70.34	59.34
Heat Supplied			
i) Sludge Calorific Value (Gross)	15.18	15.18	15.18
ii) Auxiliary Fuel Fires (Gross)	48.21	54.30	32.80
iii) Sensible Heat in Combustion Air	2.13	0.86	11.36
Total	65.52	70.34	59.34
3. Potential Waste Heat Recovery (with 95% Recovery Efficiency) (10^{6} BTU/hr)			
i) Air Preheat in Gas-Air Heat Exch.	-	-	10.78
ii) Waste Heat Steam with Boiler Exit Gas Temperature = 500^{o}F	20.35	31.45	14.20
4. Net Energy Demand (10^{6} BTU/hr)			
Auxiliary Fuel Fired	48.21	54.30	32.80
Less Waste Heat Steam Recovery	-20.35	-31.45	-14.20
NET ENERGY DEMAND	27.86	22.85	18.60

equipped with waste heat boilers provided more waste heat steam production than did boilers on multiple hearth furnaces.

ECONOMICS OF WASTE HEAT RECOVERY

The economics of air pre-heating in the hot windbox fluid bed incinerator will always be favourable if full air pre-heat temperatures can be utilized. This depends on the net thermal demand of the particular sludge. The cost benefits become marginal for sewage plant sizes of less than 10 Imgd.

The potential benefits of installing a waste heat boiler on an incinerator is a more complex matter, and will require a detailed analysis for each given situation. Many factors must be considered, the major ones including:

1. Plant Size - Assuming high percent utilization of waste heat steam, the cost benefits increase substantially with plant size. A boiler is uneconomic for plant sizes below 10 Imgd.
2. Steady, High Percent Utilization of Steam Produced - The quantities and demand variation of the potential uses must be carefully assessed. A number of potential uses will include:

   A. Process heating in liquid section of sewage plant, e.g. thermal conditioning, cake drying, etc.
   B. Building heating, subject to seasonal variation.
   C. Reheating of incinerator stack plume.
   D. Sale to another user located near plant boundary.
   E. Generation of power either by turbine-driven equipment or electrical operation using a turbo-generator. Normally equipment turbine drives can only be justified in a multi-unit plant where sufficient units have electric drives to enable start-up and continued operation during upsets.

3. Cost Effectiveness of Steam Uses - This will depend on the purchased energy costs available to the plant, namely,

auxiliary fuel and electrical power. With the existing costs of fuel and power in Southern Ontario, the value of waste heat steam for process or building heating is considerably higher than it is for straight conversion to electricity. Where the waste heat steam supplants process steam produced in an on-site package boiler, its values will amount to about $3 per million Btu based on purchased fuel cost of $2/million Btu. The value of waste heat steam for complete electricity generation is less than $1/million Btu on the basis that power can be purchased for $0.015/kwh. Electrical generation becomes significantly more effective if extraction turbogenerators are used and a major fraction of the steam can be extracted at low pressure for process or building heating (so called co-generation method).

RELATIVE ECONOMICS AND IMPACT ON PLANT DESIGN

When sewage sludge is incinerated the cost is dependent on the moisture content of the sludge, the incinerator off-gas temperature and the excess air requirement. The significance of each of these factors was explained earlier.

The most important of these factors is the sludge moisture content. The drier the sludge, the lower the annual incineration cost. The optimum moisture content is obtained when no auxiliary fuel is required. As the moisture content increases, additional auxiliary fuel is required and the annual cost of incineration increases.

In designing an incineration system as a part of the overall plant, it is necessary to carefully examine various conditioning and dewatering systems which will produce the lowest moisture content sludge for the particular plant size. Some conditioning and dewatering systems, because of their complexity, may not always be suitable for all plant sizes. For example, thermal conditioning may not be suitable for plants of a size less than 50 Imgd.

The various conditioning and dewatering systems which should be examined include:

1. Chemical conditioning of digested sludge with dewatering by vacuum or pressure filters.
2. Chemical conditioning of raw sludge with dewatering by centrifuges.
3. Thermal conditioning of raw or digested sludge with dewatering by vacuum or pressure filters.
4. Conditioning of sludge with chemicals and waste fibre slurry with dewatering by vacuum filtration and V-disc pressure filters.

The conditioning and dewatering costs per ton of dry solids varies from a low of $30 per ton for thermal conditioning to a high of $70 per ton for chemical conditioning for plant sizes of approximately 50 Imgd.

For incineration, the costs per ton of dry solids for fluidized bed and multiple hearth incineration are compared as follows for plant sizes of 50 Imgd and without heat recovery.

For wet sludges (80-85% moisture content), the cost of fluidized bed incineration would be about $80-90 per ton dry solids and the cost of multiple hearth incineration would be about $120-140 per ton dry solids.

For dry sludges (45-55% moisture content), the cost of fluidized bed incineration would be about $20-30 per ton of dry solids and the cost of multiple hearth incineration about $30-40 per ton of dry solids.

If waste heat boilers are installed and a firm use for the recovered heat is established then these incineration costs can be reduced by approximately 20-30% for fluidized bed incinerators and 10-20% for multiple hearth incinerators. The percent reduction is dependent on the amount of heat available to be recovered in the incinerator off-gases. The installation of the waste heat boiler will, however, increase the capital cost of the incinerator system by approximately 25%.

COMPOSTING SEWAGE SLUDGE BY MEANS OF FORCED AERATION AT WINDSOR, ONTARIO

John Faust and Louis S. Romano
Pollution Control Branch of the Public Works Department
Corporation of the City of Windsor

INTRODUCTION

In the summer of 1973, the Western Sanitary Landfill site in the City of Windsor was closed to refuse and sewage sludgecake and as a result the sludgecake from the pollution control plants has to be hauled to a county sanitary landfill site some 25 miles away for disposal. As a result, the cost of haulage to and disposal at the site increased substantially. Alternatives to this method of disposal were looked at by Pollution Control personnel with the intention of selecting a more economical method of sludgecake disposal. The aerated rapid composting process developed by the U.S. Department of Agriculture at its research laboratories in Beltsville, Maryland, came to our attention in late summer of 1976. Mr. L.S. Romano, Director of Pollution Control, Mr. William Newman, Superintendent of the West Windsor Pollution Control Plant and others made field trips to Beltsville to review the process. All were impressed with what they saw and especially so with the appearance of the finished product. Since looks and first impressions can be misleading, Mr. Romano decided to evaluate the process on home grounds in regards to cost effectiveness and to determine if the end product would be acceptable as a soil conditioner for developing the now defunct Western Inert Landfill site into a park and recreational area. With the invaluable assistance of Dr. Eliot Epstein, Soil Scientist at the Beltsville Laboratories, experimental piles were built at the West Windsor Pollution Control Plant in 1977.

Before the City undertook any experimentation a public hearing was held to gain approval from the Environmental Assessment Board. Approval was given by the Board with the condition that the Metro Windsor Essex County Health Officer monitor the composting process to assure

that the final compost is safe and free of pathogens and acceptable for use on public land. The data and test results reflect our endeavours during the 1977 calendar year.

The purpose of this presentation is to relate our findings as well as efforts in evaluating the forced aeration composting process.

WEST WINDSOR POLLUTION CONTROL PLANT

This plant has a present capacity of 23 mgd and with completion of the current expansion this capacity will increase to 36 mgd. Treatment consists of primary sedimentation, phosphorus removal and disinfection.

Average removal efficiencies of BOD, SS and phosphorus are 68%, 82% and 82%, respectively. One ton of dry solids is recovered per million gallons of flow treated. The primary/chemical sludge is pumped from the clarifiers to the dewatering building where vacuum filters and centrifuge serve as dewatering devices. The raw sludge has a solids content of approximately eight percent which is increased to 26 percent when dewatered by centrifuge and to 20% when dewatered by vacuum filter. Approximately 35,000 wet tons of sludgecake require disposal. I should point out at this time that only a portion of this quantity was used to build the experimental compost piles in 1977.

SITE PREPARATION

Tiling

The composting site is located directly behind the treatment plant and encompasses an area of six acres. This area was graded and tiled with four-inch diameter round field tile placed 25 feet apart and sloped to drain into a sewer discharging to the pollution control plant. Any leachate as well as groundwater is thereby intercepted and treated.

Mix Pad Construction

To facilitate the mixing of woodchips with sludge, a 100' x 150' wire reinforced concrete pad was constructed with a curb on one side and a catch basin in the centre. All drainage from this pad is directed to the treatment plant.

Electrical Power Distribution Line

Electrical power is necessary for the composting aeration system. Accordingly a triplex powerline carrying 120/208 volts was erected on five regular hydro poles. At each pole are four duplex receptacles each having its own 15 amp. breaker at the motor control panel.

EQUIPMENT AND MATERIAL REQUIREMENTS

Front-end loader

The materials compost, woodchips and sludgecake are relatively light in weight (1800 lbs/cu yd) and can therefore be handled with a 2.0 cu yd loader equipped with a 3.5 cu yd bucket. The loader should have the highest lift possible and a minimum dump clearance of eight feet.

Blowers

Each pile is made up of approximately 120 tons of sludge and 240 cu yds of woodchips and requires a blower having a 1/3 hp motor, nine inch fan operating at 3450 rpm and displacing 335 cfm at four-inch static pressure. A Dayton Model 7C504 meets these requirements.

Blower Covers

Shelters are needed to protect the blower and timer from rain and snow. A convenient cover is an inverted 45-gallon drum with the cover removed; it fits over the blower which should be resting on a platform to protect it from ground moisture. A wooden cover consisting of a lower box with an upper cover resting on the lower box is used at the West Windsor composting site. By removing the cover, the blower and timer are exposed for adjustment or maintenance.

Timer

The blowers operate intermittently in order to maintain an optimum level of oxygen in the piles. This "on" "off" cycle is controlled with a 24-hour 115 VAC timer of two-minute intervals. A Dayton 2E 131 is satisfactory.

Solid and Perforated Plastic Pipe

Approximately 200 feet of four-inch perforated plastic drainage pipe and 25 feet of solid plastic drainage pipe are needed per pile for connecting the pipe to the blower and from it to a small pile of screened compost for odour removal.

Plastic Tees and Couplings

Four-inch units are needed to connect the perforated and solid pipe.

Woodchips

Woodchips are mixed with the sludgecake for the following reasons:

(a) reduce the moisture content of the sludge to 50 to 60 percent,
(b) to improve the structure of the mixture so that air can pass through the mass,
(c) it serves as a source of carbon for optimization of the composting process which requires a C/N ratio of 30:1. Sludgecake generally has a C/N ratio of 9 to 15.

Approximately 240 cu yd of woodchips are required per pile containing 120 tons of sludgecake. Eighty percent of these chips are recovered by screening the cured material.

Compost Screening Equipment

Morbark fiber screen

The cured material is transferred from a curing pile to the screening system by means of front-end loader. The material is deposited into a 10 cu yd hopper at the head of the Morbark screen where four bridge breakers keep the material flowing into four feed augers. The feed augers systematically feed the material to the rotating disc separator with 1/2" openings. The separated woodchips are conveyed by a chain flyte conveyor to a holding pad for reuse.

Sweco vibro energy screen

The fine material is conveyed from the Morbark screen to the Sweco screen of 1/4" screen openings. Woodchips and woodshavings larger than 1/4" are reused in building subsequent compost piles, while the fine material or compost is conveyed to an enclosed area and subsequently moved to a storage area.

This screening system can process approximately one cubic yard of compost per minute.

Tractor-Rototiller

Tractor

The sludgecake and woodchips are mixed at a ratio of 1:2, respectively, by volume by means of a farm tractor-rototiller. A 40 hp tractor with three point hitch hydraulic system and power-take-off is used.

Rototiller

This is a Kuhn Model EL60 with a three speed gear box and has a width of 60 inches.

Miscellaneous

Duct tape, caulking compound for sealing blowers and pipe connections, shovels and tools are needed.

MONITORING REQUIREMENTS

Temperature

The aerobic decomposition of sludgecake generates heat and causes the temperature to rise inside the pile. Dr. Epstein has suggested a minimum temperature of 60^{o}C for a minimum of 19 days to achieve optimum composting and a satisfactory reduction in pathogenic organisms. Daily temperature readings are taken by means of a portable battery operated multirange temperature indicator manufactured by Atkins Instruments (Model 23108-30).

Oxygen

Oxygen values of gases in the pile should range from five to fifteen percent. Lower values indicate inadequate aeration and higher values indicate excessive aeration. Daily oxygen readings are taken by means of portable oxygen analyzer manufactured by Teledyne Analytical Instruments (Model No. 320B IRC).

PROCEDURE OF BUILDING COMPOST PILES

The four-inch flexible, perforated drainage pipe is laid in a "U" shape (60' long and 16' wide) on the ground. It is then covered with 15 inches of woodshavings or fine woodchips. This layer absorbs liquids seeping from the pile and prevents clogging of the pipe.

On the mixing pad approximately 20 cu yd of woodchips are spread out in a layer eight feet wide and ten inches thick. Ten cubic yards of sludge are then deposited on the woodchips by the unloading tandem truck hauling the sludgecake from the dewatering building to the composting site. The woodchips and sludgecake are mixed by means of the tractor-rototiller until a homogeneous mixture is obtained. This mixture is then placed in a pile on the prepared base. A full day's production of 120 tons of sludgecake will yield a pile 70 feet long by 32 feet wide and 8 feet high. The entire pile is covered with 10 to 15 inches of screened compost. If screened compost is not available unscreened compost can be used. Proper coverage of piles with compost is necessary in order to keep malodorous gases from escaping from the pile surface as well as to provide insulation for heat equialization and thermophilic decomposition.

A solid piece of pipe is used to connect the perforated pipe which is under the pile to a blower that is driven by a 1/3 horse power motor. Suction is applied for at least 21 days. The gases that are removed from the pile during the suction are piped into an adjacent small pile (1 1/2 cu yd) of screened compost which has the capability of absorbing odours effectively.

Since the gases which are removed from the pile during the suction period are warm and water will condense in the pipe outside the pile, a water trap is placed in line with the suction pipe and is located between the pile and the blower.

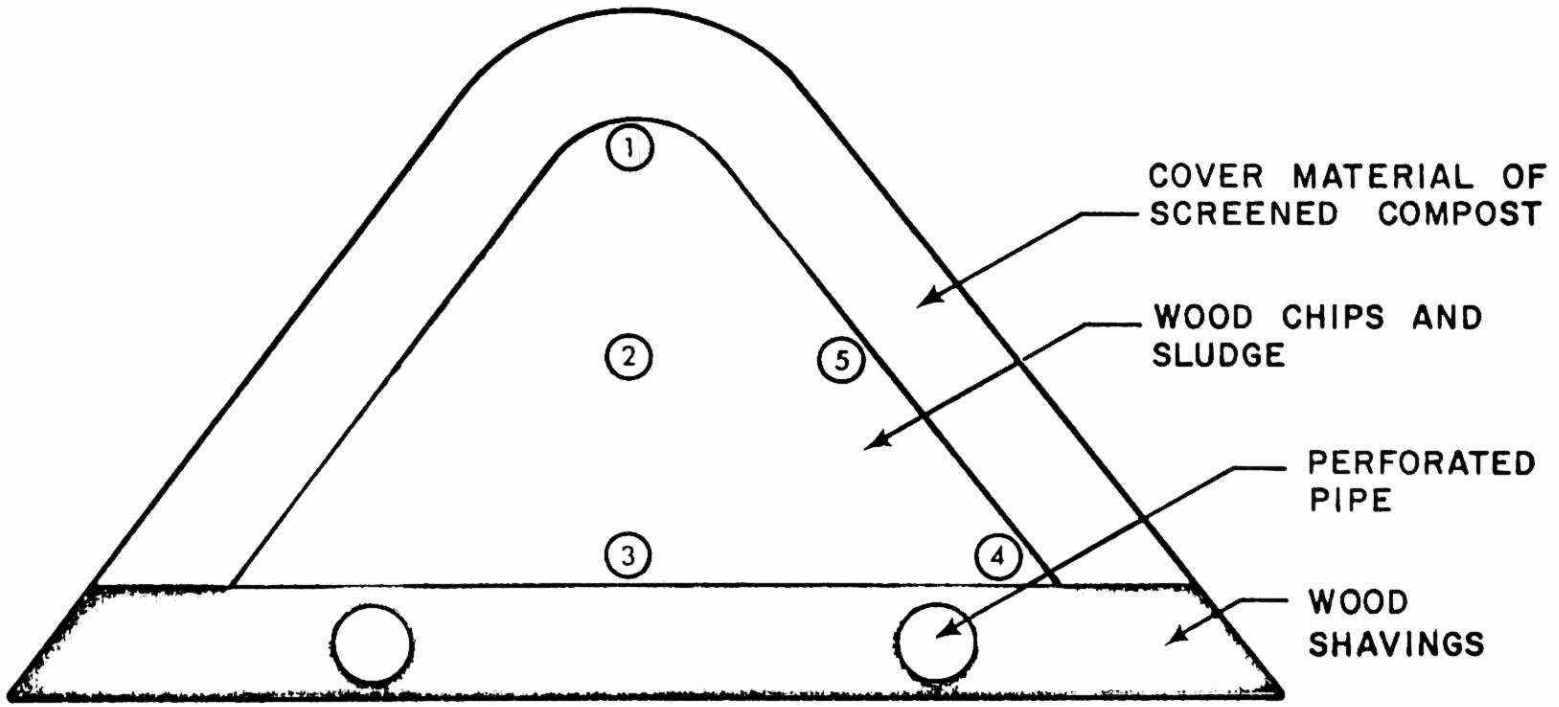

FIGURE 1. CROSS - SECTION OF A COMPOST PILE SHOWING TYPICAL SAMPLING POINTS

PROCESS MONITORING

Bacteriological Examinations

On the 21st day of composting each pile was opened and samples were taken using sterilized utensils at locations shown in Figure 1. It will be noted that sampling points 1, 4 and 5 are at the interface of sludge and cover material. These sites at the periphery next to the cover are usually the coolest spots in a pile.

While raw sludge samples, as exhibited in Table 1, contained coliforms of the order of 10^8/100 grams, fecal coliform of 10^7/100 grams and streptococcus fecalis of 10^7/100 grams and various types of salmonella, of which organienburg, saint-paul and thomasville were most predominant, none of the latter were found in the process material after 21 days of composting.

Table 2 shows that 98 samples of process material were collected from 20 separate piles and only seven samples contained total coliform, four samples contained fecal coliform and three contained fecal strep of the order of 10^3/100 grams or less. Samples taken from location four and five as shown in Figure 1, or the coolest spots, contained coliform bacteria. This deficiency was overcome by increasing the depth of the cover material at these locations. No salmonella, shigella were isolated from any of the 98 samples. While parasite eggs were found in the raw sludge none were found in the processed material.

All samples for bacteriological examinations were taken in the presence of a public health inspector and the examinations were performed by the local laboratory of the Ontario Ministry of Health under the direction of Miss Ann Prytula.

Temperature and Oxygen Readings

Temperature

Daily temperature readings were taken at each pile at various locations to include the spots on the periphery as well as those inside the pile. Anywhere from six to fourteen readings were taken at each pile and recorded.

Figure 2 shows the temperature profile of one of the first piles that was built. Shown on the graph is the daily average temperature

TABLE 1. COLIFORM POPULATIONS AND SALMONELLA TYPES ISOLATED FROM RAW SLUDGE SAMPLES - CITY OF WINDSOR

Total Coliform	/100 g	43×10^8
Fecal Coliform	/100 g	32×10^7
Fecal Streptococcus	/100 g	33×10^7

Salmonella Types:
Agona, Schwarzengrund, Give, Eimsbuettel
Most Predominant:
Organienburg, Saint-Paul, Thomasville

NOTE: Bacteriological examinations were performed by the local laboratory of the Ontario Ministry of Health.

TABLE 2. COLIFORM AND SALMONELLA ISOLATIONS AFTER 21 DAYS OF COMPOSTING - CITY OF WINDSOR

98 Samples were examined:
7 Samples contained total coliform
4 Samples contained fecal coliform
3 Samples contained fecal strep
No Salmonella, Shigella or Yersinia enterocolitica were isolated in any of the samples.

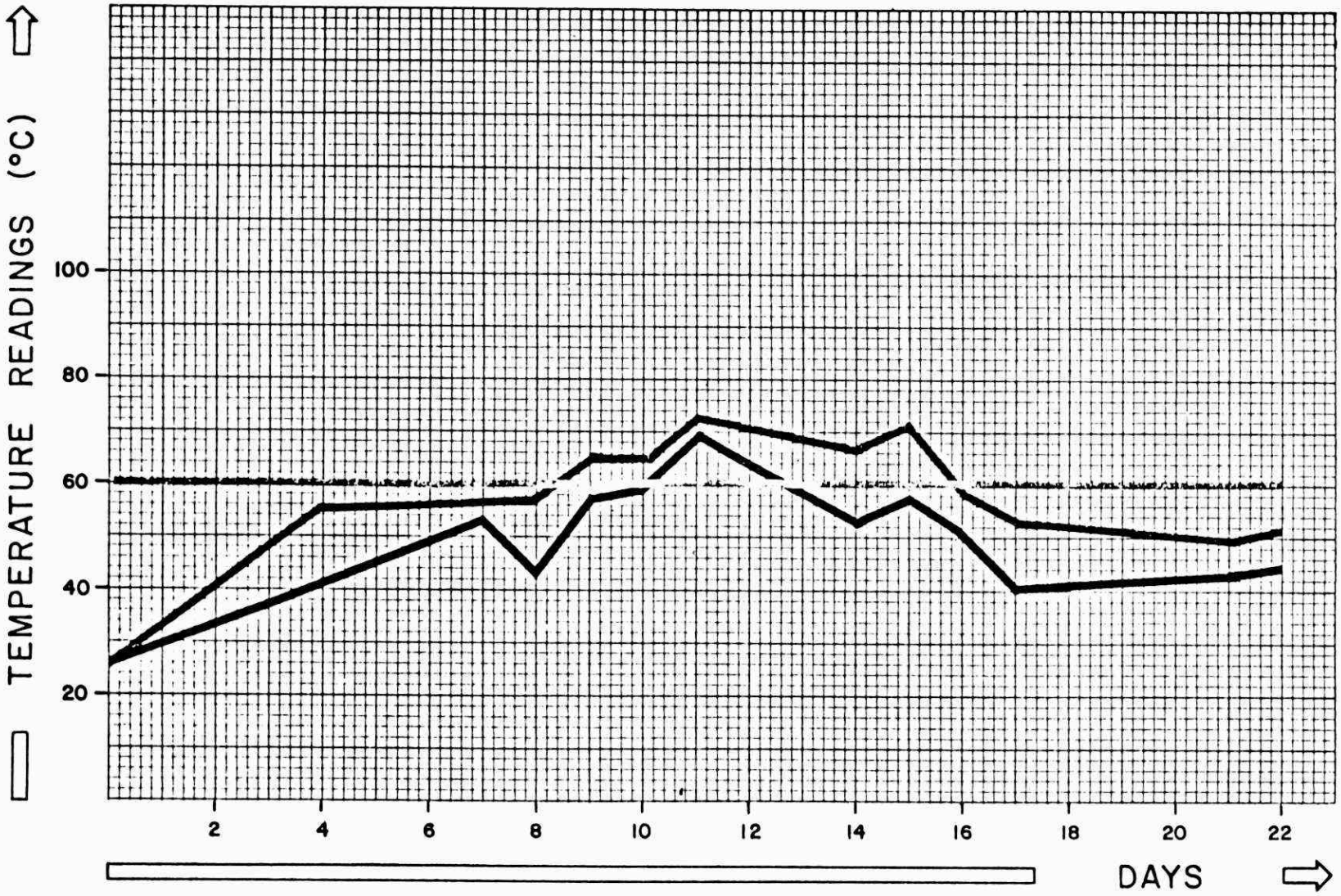

FIGURE 2. AVERAGE AND LOW TEMPERATURE READINGS WITHIN A PILE

reading as well as the lowest reading. It will be noted that nine days elapsed before the average temperature within the pile exeeded the 60°C level and ten days before the lowest reading reached 60°C. These readings represent a pile where insufficient screened compost was available for cover material. The cover material consisted of woodchips and woodshavings which do not have the same insulation efficiency at the same thickness as screened compost.

Figure 3 shows the average and low temperatures within a pile that was insulated with 12 to 15 inches of screened compost. The temperatures exceeded the 60°C level on the third day of composting and remained in the thermophilic range for the duration of the composting period of 21 days. It should be noted that the maximum difference between the daily average temperature and the daily low was six degrees centigrade. This too is indicative of a properly insulated pile.

Oxygen readings

Daily oxygen readings were taken with a portable battery operated oxygen analyzer. The aeration rate was adjusted to maintain an oxygen level between 5 and 15% in the pile for rapid decomposition of the sludge. This level can be achieved with an aeration rate of about 500 cubic feet (14 m^3) per hour per ton of sludge (dry weight basis) and by adjusting the blower on-off cycle.

COMPARISON OF CHEMICAL COMPOSITION OF SLUDGECAKE WITH SCREENED COMPOST

Sampling of Sludgecake

Composite samples of sludge were collected by taking approximately 30 grab samples of approximately 50 grams each from the 120 tons of sludgecake that were hauled to the mixing pad for each pile that was built.

Sampling of screened compost

Composite samples of the screened material were collected by taking 50 grams for each two cubic yards of unscreened material dumped into the screen hopper. The grab samples representing each pile were composited in a stainless steel pail, mixed and aliquots thereof were taken for chemical analysis.

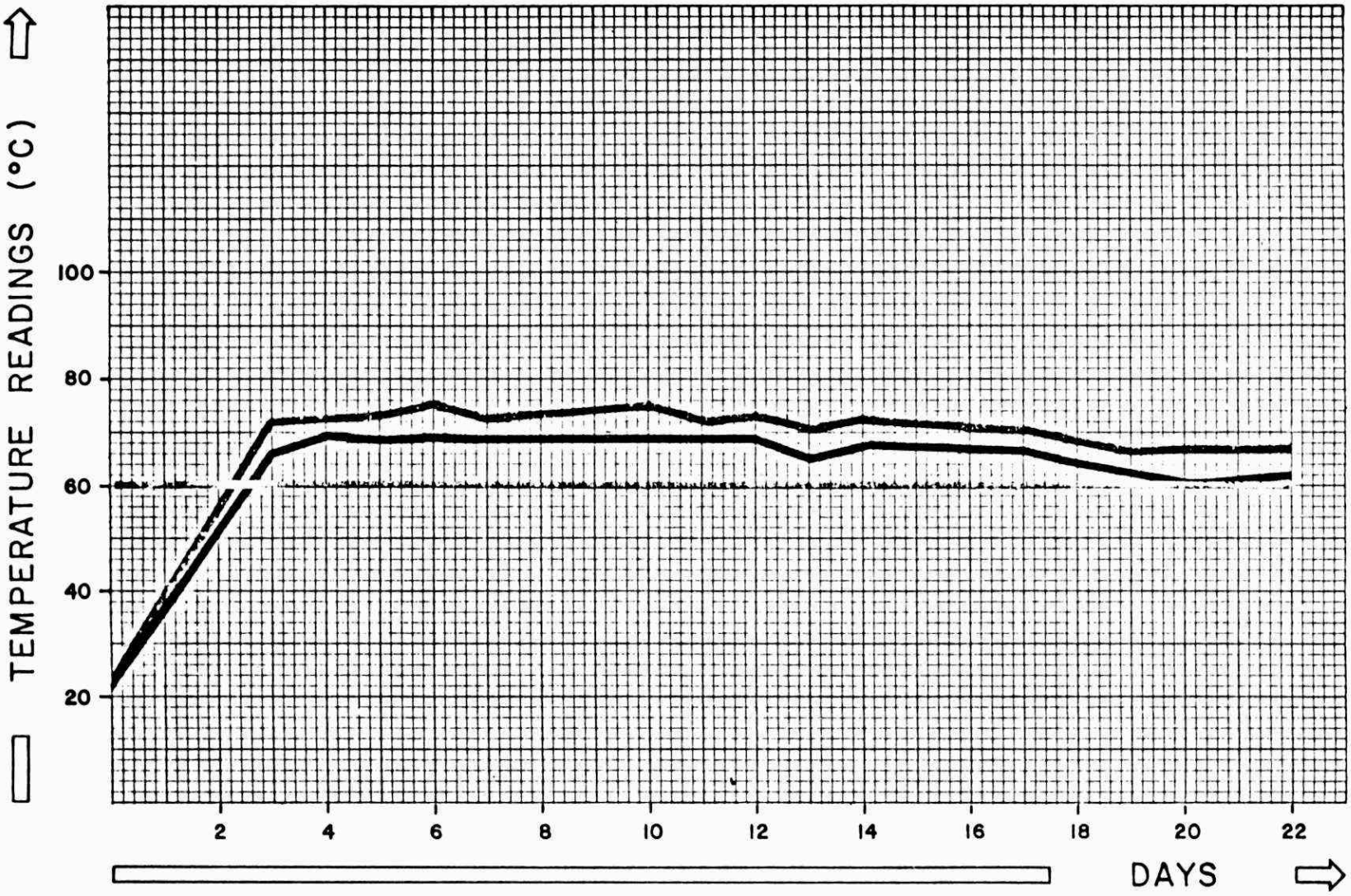

FIGURE 3. AVERAGE AND LOW TEMPERATURE READINGS WITHIN WELL-INSULATED PILE

Method of testing

Sludgecake and screened compost samples were analyzed in accordance with Standard Methods for the Examination of Water and Wastewater. Heavy metals were analyzed by using a Varian AA6 atomic absorption spectrophotometer.

Chemical Composition

Table 3 exhibits the respective solids content and nutrient values of both sludgecake and screened compost. Since the thermophilic process generates high temperatures in the piles a continuous emission of water vapor from the piles takes place; it is not uncommon to observe steam coming from the piles even on warm days. This reduction in moisture increases the solids content of the screened compost to an average of 57.7%. It will be noted that while the nutrient values in the sludgecake are quite low at 2.6% total nitrogen and 2.4% phosphorus, they are even lower in the screened compost. Nutrients are reduced in concentration by a factor of approximately three. This is due to the dilution effect of the woodchips and woodshavings which become an integral part of the screened compost.

Table 4 exhibits the heavy metal contents of both sludgecake and screened compost. Again there is a decrease in concentration. The iron content in the compost is 2.2% because ferric salts are used for the removal of phosphorus from the sewage entering the pollution control plant.

Table 5 shows the heavy metals in the screened compost and the suggested maximum permissible concentration in compost which may be used by home gardeners. These provisional guidelines were prepared by the joint committee of the Ontario Ministry of Agriculture and Food and the Ontario Ministry of the Environment. It will be noted that each constituent except chromium meets these guidelines. In order to assure ourselves of continuous compliance with these guidelines we have upgraded the specifications regarding heavy metals in the ferric solutions purchased for phosphorus removal as these are known to contain heavy metals. More vigilant enforcement of the Industrial Waste By-law is also necessary.

TABLE 3. COMPARISON OF CHEMICAL COMPOSITION OF SLUDGECAKE WITH SCREENED COMPOST - CITY OF WINDSOR.

Constituent	Sludgecake	Compost
Solids	23.1%	57.7%
Volatile (% of dry solids)	51.1%	51.6 %
Ammonia - Nitrogen	1590 mg/kg	480 mg/kg
Kjeldahl - Nitrogen	2.6%	0.85%
Phopshorus as P	2.4%	0.67%
Potassium as K	-	0.07%

NOTE: Test data represents nine composite samples of sludge and compost.

TABLE 4. COMPARISON OF CHEMICAL COMPOSITON OF SLUDGECAKE WITH SCREENED COMPOST - CITY OF WINDSOR

Constituent	Sludgecake	Compost
Cadmium as Cd	19 mg/kg	4.9 mg/kg
Chromium as Cr	1,230 "	230 "
Copper as Cu	350 "	150 "
Iron as Fe	55,600 "	22,300 "
Nickel as Ni	240 "	77 "
Lead as Pb	290 "	160 "
Zinc as Zn	2,660 "	960 "

NOTE: Test data represents nine composite samples of sludge and compost.

TABLE 5. HEAVY METALS IN SLUDGE COMPOST WITH RESPECT TO ENVIRONMENTAL GUIDELINES

Constituent	Compost	Provisional Guidelines*
Cadmium	4.9 mg/kg	6 mg/kg
Chromium	230 "	200 "
Copper	150 "	400 "
Nickel	77 "	80 "
Lead	160 "	300 "
Zinc	960 "	1,200 "
Mercury	0.3 "	4 "

* Suggested maximum permissible concentration in compost for use by home owner prepared by joint committee of Ontario Ministry of Agriculture and Food, and Ontario MOE.

COMPARISON OF COST OF DISPOSAL OF SLUDGECAKE AT THE COUNTY LANDFILL WITH THE COST OF COMPOSTING BY MEANS OF FORCED AERATION

Cost of Disposal at the County Landfill

Table 6 shows this data. The annual cost to haul a total of 35,000 tons of wet sludge to the county landfill by outside contractor is $154,000 and the annual cost of disposal at the site is $84,350, for a total cost of $238,350. When this is expressed in dollars per dry ton of solids removed it works out to $34.05.

Cost of Composting

Site preparation

The cost of grading, tiling the site and building a mixing pad was $85,300. This is amortized over a 10-year period for an annual cost of $8,530.

Woodchips

Since only 80% of the woodchips can be recovered per cycle of composting, an additional 10,000 cubic yards of woodchips are required annually for a total cost of $55,000.

Screens

The capital cost of the Morbark and Sweco screening machinery including the electrical control panel and electrical hook-up was $115,000. By amortizing this over an estimated 10-year useful life, the annual cost is $11,500.

Materials handling equipment

To transport the sludgecake from the dewatering building to the mixing area one tandem truck is needed and for the spreading of woodchips, moving the mixture and compost, two front-end loaders and one tractor with rototiller are required. It is anticipated that this equipment will have a useful life of eight years. The annual cost including fuel and maintenance is estimated to be $89,100. The City did not purchase this equipment as an outside contractor is expected to provide same.

TABLE 6. COST COMPARISON OF SLUDGE HAULAGE AND DISPOSAL WITH COMPOSTING

A.	County Landfill Disposal:		
	Annual Haulage Cost	$ 154,000	$ 238,350
	Annual Disposal Cost	$ 84,350	
B.	Composting:		
1	Cost of Site		$ 8,500
2	Woodchips		$ 55,000
3	Screens, Housing, etc.		$ 11,500
4	Materials Handling Equipment:		
	2 Front End Loaders	$ 58,000	
	1 Tandem Truck	$ 20,700	
	1 Tractor - Rototiller	$ 10,400	$ 89,100
5	Fans, Drainage Pipe		$ 16,000
6	Manpower:		
	3 Men at $ 20,000		
	1 Foreman $ 25,000		$ 85,000
7	Maintenance and Power		$ 8,000
			$ 273,100

NOTE: 35,000 tons of sludge = 17,000 cu yd of compost.

Fans, drainage pipe

Additional blowers complete with timers will be required as will be 26,000 feet of four-inch plastic drainage pipe, and tees and couplings at an estimated total cost of $16,000 annually.

Manpower (three men and one foreman)

To operate the front-end loaders and tractor-rototiller three operators and one foreman to supervise the composting operation are needed. The annual salaries paid to the operators including fringe benefits is $20,000 and the foreman $25,000. Total cost of manpower is $85,000.

Maintenance

To maintain the machinery and supply electrical power to the blowers and mechanical screens the estimated cost is $8,000 annually.

The estimated total annual cost of composting 35,000 tons of sludgecake is therefore $273,100. Expressed on a dry weight basis this amounts to $39.01 per ton.

This is approximately five dollars per ton more than hauling it to the landfill disposal site. Notice should be also made of the fact that 35,000 tons of sludgecake will yield approximately 17,000 cubic yards of screened compost. While it is difficult to estimate the value of the screened compost I should point out that a local entrepreneur who is composting sewage sludge into a soil conditioner by the windrow method charges $10 per yard of material when purchased in bulk. The City does not anticipate a return of $170,000 annually for the compost it will produce but it will realize a benefit by using the compost for land reclamation and park beautification.

PROPOSED USES FOR THE COMPOST

The now defunct landfill site in the City encompasses approximately 160 acres which are scheduled to become a green or recreational area and ski slope, since it is the only hill within 30 miles of Windsor. The present cover material at this site consists of impervious clay which is naturally infertile and useless from a horticulturist's point of view. The Parks Commissioner for the City estimated that approximately 150,000

cubic yards of topsoil would be required for establishing a seedbed for grass and for planting trees. This volume of topsoil, if it were available, would cost the City in excess of $1,000,000 or approximately $100,000 annually over the next 10 years. In place of topsoil, the City's Parks Department intends to spread compost on the existing cover material for a depth of four to six inches and then incorporate it into the clay by rototilling and discing. At least ten years' production of compost will be required to meet the Parks Department's requirement for one project alone. The anticipated annual saving of $100,000 by using compost in place of topsoil will more than off-set the additional cost of composting the sewage sludgecake.

CONCLUDING REMARKS

a) Composting is a method to treat waste and at this point in time not a moneymaker.
b) By composting sewage sludgecake the odours are alleviated and a stable humus-like organic material is produced.
c) The exothermic process generates temperatures within the pile that effectively destroy many of the human pathogens.
d) While composting is more labour intensive than some of the other systems of sludgecake disposal it is not capital intensive.
e) The end product can be utilized as a soil conditioner in publicly owned parks and recreational areas, and it could also be used by the agricultural industry in the production of field crops.

UNITED STATES SLUDGE DISPOSAL REGULATIONS
IMPACTS UPON SEWAGE TREATMENT AGENCIES
COMPARISONS WITH EXPERIMENTAL RESULTS

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INTRODUCTION

In the early days of wastewater treatment, it was believed that biological degradation of the sludge produced by wastewater treatment would leave little or no residue. This, of course, was never realized. Whether it be Imhoff tank, trickling filter or activated sludge process, solids are produced which eventually must be disposed of, no matter what sludge treatment process is employed. Even incineration leaves considerable amounts of ash (usually 30% of the solids by weight) which is difficult to dispose of in an environmentally acceptable manner. The sludge disposal problem is, of course, a product of modern technological advances. The United States has come a long way since the last quarter of the 19th century in wastewater treatment. In 1900, there were 60 municipal treatment plants in the U.S. serving a population of 1.0 million people [1]. By 1935, there were approximately 3,700 municipal plants serving 25.5 million people [1]. In 1968, it was estimated that approximately 114 million people in the U.S. were served by some form of treatment or approximately 78% of the existing population [2].

The U.S. has been estimated to produce 10,000 dry tons (9,072 metric tons) per day of sludge, and this amount is expected to increase to 13,000 dry tons per day (11,800 metric tons per day) by 1990 [3]. The disposal of these amounts of solids is a most difficult problem facing the U.S. today. In general, there exists sufficient technology to remove various pollutants from wastewater, but the disposal of the resulting

solids have been a difficult technical as well as social and aesthetic problem.

Although the sludge processing technology utilized today may be very sophisticated, a product always remains from such processing which must be either disposed of or utilized. The product eventually finds its way either to land, water or air, and the consequence must be evaluated. In addition, no process we choose today, no matter how sophisticated, can be justified if it has a high energy consumption rate.

Incineration is attractive to many today, since the resulting product is an inert ash which is smaller in volume and aesthetically more acceptable to citizens. However, the process releases significant quantities of air pollutants if operated without sophisticated and expensive air pollution control devices. Of even more concern, however, in today's energy situation, is the amount of fuel required for this process which in 1974 averaged 51.6 gallons (195 L) of number of 2 fuel oil to burn one ton (.907 tonne) of dry solids [4]. Even more alarming is the fact that this fuel would be used to destroy the nitrogen value of sludge, since 917 gallons (3470 L) of number 2 fuel oil are required to produce 1 ton (.907 tonne) of nitrogen.

Ocean disposal has been utilized by many coastal cities, notably, Philadelphia, Los Angeles, and New York for the ultimate repository of their municipal sludge. However, in the U.S. this method is considered by the Federal government to be detrimental to ocean-front recreational activities and aquatic life, and will probably be eliminated by 1981 [5].

Landfilling of sludge is utilized by many municipalities for sludge disposal. The chief drawback to this method of sludge disposal is that it essentially negates the use of land for other more productive purposes, and there is often insufficient landfill space available in urban areas for solid waste disposal.

Because of the above noted drawbacks of ocean disposal, incineration and landfilling, municipalities have turned to utilizing municipal sludge as an agricultural fertilizer and soil amendment for upgrading barren soil. For example, the Metropolitan Sanitary District of Greater Chicago (District) began in 1971 to purchase land in Fulton County,

Illinois, for application of lagooned digested sludge. In 1977, the District owned 15,528 acres (6,284 ha) of continguous land in Fulton County, and the site was accepting nearly 250 dry tons (253 tonnes) per day of liquid digested sludge. Other large cities in addition to Chicago that are embarking on their own land application schemes or seriously considering such action include Los Angeles, Milwaukee, San Francisco, Denver and Philadelphia.

Although there are obvious engineering problems to be solved in implementing a land application scheme, the major stumbling block for this method is the attitude of regulatory agencies regarding the metal uptake by plants fertilized with sewage sludge. This has for many municipalities been the chief reason why they have been reluctant to endorse a land application scheme for sludge management. In particular, the probability of adverse state, local and federal regulations in this area is high; and such restrictions may make land application economically unattractive. In such an atmosphere, many municipalities are reluctant to commit capital and operating funds to land application until the regulations become more definitive and effective.

This paper will discuss in some detail the existing and/or proposed land application regulations of the States of Wisconsin, Illinois, Indiana and Ohio as well as those of the Federal government of the U.S. In addition, the impact of these regulations will be presented in terms of loading rate restrictions. Lastly, the proposed and/or existing state and federal regulations will be compared with data from research projects where metal uptake from sludge application was studied. This paper will focus its attention upon those aspects of the regulations which deal with metal uptake by crops fertilized with sludge.

U.S. GUIDELINES AND/OR REGULATIONS

Federal EPA Technical Bulletin

On November 2, 1977, the United States Environmental Protection Agency (EPA) published in the Federal Register its Technical Bulletin [5] on municipal sludge management. This Technical Bulletin was not written as a regulatory document or design manual but was prepared to assist EPA regional administrators in evaluating grant applications for

construction of publicly owned treatment works. As such, then, its exact status is difficult to determine. It would appear, however, that unless a municipality can show good reasons for deviation from the Technical Bulletin, the awarding of an EPA construction grant could be placed in jeopardy.

The Technical Bulletin states that the pH of the soil/sludge mixture should be controlled and that a pH above 6.5 will minimize metal uptake by plants. This concept of higher soil/sludge pH while desirable may be impractical for most agricultural operations. The Bulletin takes notice of the fact that the use of sludge for strip mine reclamation may preclude maintaining soil pH above 6.5, but states that if sludge is not effective in raising the pH above this level, liming may be necessary.

The Bulletin states that experience has shown that the total accumulations of metals listed in Table 1 have not led to observed problems.

TABLE 1. TOTAL ACCUMULATIVE METAL APPLICATION TO SOIL U.S. EPA TECHNICAL BULLETIN, NOVEMBER 2, 1977, FEDERAL REGISTER

Metal	Soil Cation Exchange Capacity (meq/100 g)		
	0-5	5-15	> 15
	Amount of Metal (kg/ha)		
Pb	500	1,000	2,000
Zn	250	500	1,000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20

The Technical Bulletin states that annual cadmium loadings that have been used with minimum plant cadmium uptake have ranged from 1 kg/ha to 2 kg/ha. However, the language of the Bulletin suggests that annual loadings over 1 kg/ha should include monitoring and the growing of select crop species.

The entire Bulletin is replete with references to the Resource Conservation and Recovery Act (1976). The EPA was given authority by this act to issue regulations for municipal sludge application to land, and it appears that the EPA will rely on this power to issue regulations for municipal sludge application to land.

Proposed Regulations for Classification of Solid Waste Disposal Facilities

The Solid Waste Recovery Act as amended by the Resource Conservation and Recovery Act of 1976 requires that the EPA promulgate regulations containing criteria for determining which facilities shall be classified as sanitary landfills and which shall be classified as open dumps.

On May 12, 1977, the Office of Solid Waste of the EPA issued a working draft of regulations as they must according to the Resource Conservation and Recovery Act of 1976. The draft has not been through the formal EPA review and clearance process, but was circulated to selected individuals and organizations to solicit comments.

The proposed regulations do not, per se, cover municipal sludge provided such sludge contains only solid or dissolved material from domestic sewage. However, since almost all sewage contains some material which is not classified as domestic, this point is rather immaterial.

In the May 12, 1977 EPA draft, those facilities where the land spreading of solid waste takes place must comply with those regulations listed in Table 2. As can be seen, the cumulative metal loading application limits are identical to that contained in the Technical Bulletin noted earlier. The annual cadmium limits, however, are significantly different being considerably less than those in the Technical Bulletin.

There is some indication that crops used for forage and feed grain for animals can have higher yearly and cumulative applications, but this is too vaguely written for adequate interpretation.

It should be noted that the solid waste regulations do not require compliance with the metal regulations noted above for crops used for non-food chain uses. That is, the growing of nursery stock (evergreens, etc.) or landscape sod would not have to comply with the metal regulations.

TABLE 2. PROPOSED REGULATIONS FOR CLASSIFICATION OF SOLID WASTE DISPOSAL FACILITIES

Office of Solid Waste - USEPA
May 12, 1977

257.4-5 Land

A facility for the land spreading of solid waste must comply with the following:

A. Food Chain Uses

The pH of the soil/solid waste mixture is controlled to limit heavy metal uptake to plants. If municipal wastewater treatment sludge is applied, the soil/waste pH is equal to or greater than 6.5.

3. Metals

a. No greater amount of metals are cumulatively applied to the site than those listed below.

Maximum Cumulative Metal Applications

Metal	Soil Cation Exchange Capacity (meq/100g)		
	0-5	5-15	>15
	Maximum Addition (kg/ha)		
Zn	250	500	1,000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20
Pb	500	1,000	2,000

b. No greater amount of cadmium than 1 kg per ha is applied to the site on an annual basis up to 1985. After 1985, no greater amount is applied than 0.5 kg per hectare per annum.

c. Sites that are used for forage and feed grain for animals where the crop is distributed in regional markets and that are zoned to prevent the use of the land for the production of direct human food crops may exceed the limits in a. and b. above.

Wisconsin Guidelines

The Wisconsin Department of Natural Resources in Technical Bulletin No. 88 has published guidelines on sludge application to land. The "guidelines can be used for screening the land application alternative, evaluation of environmental effects...and for developing a land application program..." The guidelines restrict total applications of sludge by limiting the total "metal equivalent" applications on a pounds-per-acre basis to not more than 65 times the soil cation exchange capacity (CEC) in meq/100 g of soil. Metal equivalents of a specific sludge are calculated using the following formula:

$$\frac{\text{Metal equivalents}}{\text{ton sludge}} = \frac{(\text{ppm Zn}) + 2\ (\text{ppm Cu}) + 4\ (\text{ppm Ni})}{500}$$

In addition, yearly applications are limited to a maximum of 2 lbs/acre/yr (2.24 kg/ha) of Cd with a total application site lifetime maximum of 20 lbs/acre (22.4 kg/ha). The lifetime limitation calculates to be shorter either by the above equivalent method or the maximum application of 20 lbs/acre of Cd. Technical Bulletin No. 88 recommends maintenance of soil pH above 6.5.

The exact regulatory nature of the Wisconsin guidelines is not clear. However, the preface of Technical Bulletin No. 88 states that "it has been prepared to assist the Department of Natural Resources personnel in the granting of discharge permits..." Since no facility for sludge disposal can operate without a permit, Technical Bulletin No. 88 has the impact of regulations.

The Wisconsin guidelines are somewhat different than that of the Federal Government; however, the similarities are quite striking. Total application is absolutely limited to a total of 20 lb/acre (22.42 kg/ha) and a yearly application of 2 lb/acre (2.24 kg/ha). The absolute maximums are almost identical to those in the Federal Technical Bulletin and, of course, have the same basic philosophy behind them. Limiting equivalent metal applications to 65 times the soil CEC appears to be related to the concept put forth by Chumbley [6]. He suggested limiting total application of sludge based upon its Zn, Cu, and Ni content. This concept was advocated in the United States by Chaney [7] and was contained

in early drafts of the Federal Technical Bulletin. It is not, however, held in wide favor and has been criticized in a recent report [8] by the Council for Agricultural Science and Technology.

The concept suggested by Chumbley [6] and advocated by Chaney [7] assumes that the toxicities of copper and nickel can be expressed in terms of some multiple of zinc and that the toxicities of these three elements to plants are additive. The concept has been dropped from consideration by the Federal EPA because it was too simplistic, did not apply to many crop and soil types, and underestimated the amount of metals which could be applied to neutral soils.

Illinois Regulations

In April of 1977, the Illinois Environmental Protection Agency published its second edition of technical policy WPC-3 entitled "Design Criteria for Municipal Sludge Utilization on Agricultural Land". As yet, this document is considered a draft copy, and no adoption date has been set. The design criteria document has a section entitled "Heavy Metal Considerations" which in part is reproduced in Table 3. In addition, soil pH must be maintained above 6.5.

The Illinois regulations are designed to allow free use of sludge provided the regulations are followed. That is, a permit from the Illinois Environmental Protection Agency is not needed if the metal regulations (and other restrictions) are followed. What metal restrictions would be imposed on permitted sites is not known, since the Illinois EPA would determine this on a case by case basis. However, it can be assumed that deviations from the metal restrictions of Table 3 would have to be well justified and backed up by an extensive monitoring program.

A careful reading of Table 3 quickly reveals that the metal addition restrictions are identical to those presented in Table 1 and are in fact identical to that contained in Table 2 as well. Yearly applications could range from 1 to 4 lbs/acre (1.12 - 4.48 kg/ha) depending on soil CEC which is somewhat higher than those of the Federal Technical Bulletin or the Office of Solid Waste Regulations.

TABLE 3. ILLINOIS ENVIRONMENTAL PROTECTION AGENCY DESIGN CRITERIA FOR ALL MUNICIPAL SLUDGE UTILIZATION HEAVY METAL CONSIDERATIONS

Soil cation exchange capacity (CEC) plays a major role in enabling the soil to retain the heavy metals contained in the sludge. Soils having a CEC in the range of 5 to 15 meq/100g are generally acceptable for sludge utilization providing sludge applications do not result in heavy metals being applied to land in excess of those amounts listed below.

Maximum Acceptable Heavy Metal Concentrations over the Life of a Project Site		
Metal	lbs/acre	Maximum Annual Rate (lbs/acre)
Pb	1,000	
Zn	500	
Cu	250	
Ni	100	
Cd	10	2

There are some land areas in Illinois which have low CEC and should be avoided for sludge application whenever possible. Areas...having CEC below 5 meq/100g (may apply sludge) but must develop a management scheme that includes the following restrictions in order to qualify for minimum control of sludge users.

1. Only dried sludge may be applied.
2. Only half of the heavy metal concentrations stipulated may be applied

Permits may be issued which allow application of double the amounts listed above providing it is demonstrated that the soil CEC is greater than 15 meq/100g.

Indiana Guidelines

In May of 1976, the State of Indiana issued its third draft of "Interim Guidelines for Municipal Sludge Disposal on Land". Their guidelines for limiting sludge metal applications are identical to those contained in Table 1 and Table 2. That is, the State of Indiana has adopted the concept of the Federal Technical Bulletin and the Office of Solid Waste. Metal additions apply only to soils that are adjusted to pH 6.5 or greater when sludge is applied and are to be managed at pH 6.2 or greater thereafter. Yearly cadmium additions are limited to 2 kg/ha which is identical to that of the Federal Technical Bulletin and is the same concept put forth by the Office of Solid Waste.

Ohio Guidelines

The State of Ohio has gone through several changes in its guidelines for "Land Application of Sewage Sludge". In July of 1975, the Task Force on Land Application of Sewage, appointed by Roy M. Kottman, Director, Ohio Agricultural Research and Development Center, issued its first version of the document entitled "Land Application of Sewage Sludge", Bulletin 598. This document adopted the concept of Chumbley [6] which is the so-called "zinc equivalents" concept. The July, 1975, Ohio guideline liberally quotes early drafts of the Federal Technical Bulletin where this concept was put forth by the EPA. Clearly, the Ohio Task Force had decided to adopt the Federal Technical Bulletin sludge metal loading limits.

As noted previously, however, the final draft of the Federal Technical Bulletin does not even mention the "zinc equivalents" concept but has instead adopted specific limits on individual metals. In May of 1976, Bulletin 598 was again published. This time, however, no mention is made of the Federal Technical Bulletin, but the May, 1976, Ohio guidelines are virtually identical to those of the final draft of this document. Total metal additions are identical to those of the Federal Technical Bulletin and the Office of Solid Waste. Yearly Cd additions are limited to 2 lb/acre (2.24 kg/ha) which is similar to that of the Technical Bulletin (2.0 kg/ha).

The Ohio guide states that "metal additions apply only to soils that are adjusted to pH 6.5 or greater when sludge is applied and are to be managed at pH 6.2 or greater thereafter".

Summary

The state guidelines and/or regulations all exhibit a marked similarity to those of the Federal government. The Ohio guidelines most vividly illustrate this.

The first version of the Ohio guidelines (July, 1975) freely quoted the existing draft of the Federal Technical Bulletin. As soon as the Technical Bulletin was changed, Ohio issued a second version (May, 1976) which corresponded to the new version.

Of course, the state agencies responsible for the guidelines and/or regulations would say that they have not intentionally followed the Federal government in the drafting of sludge metal guidelines or regulations. However, it can be safely stated that there will be few States that would adopt regulations significantly different from those of the Federal government. This is because of the usual unwillingness of State agencies to risk losing federal funds. Also, the Federal guidelines and/or regulations are easily accessible and offer state agencies a ready-made document, while a different document would require significant staff time to prepare. Moreover, the use of Federal guidelines or regulations offers the states the opportunity to transfer responsibility for such guidelines to a higher branch of government, and they need not concern themselves with justification.

The guidelines of the States of Ohio, Wisconsin, Illinois and Indiana and the Federal EPA all limit total metal loadings. The total metal loading limitations of Ohio, Illinois, Indiana and the Federal EPA are identical. Wisconsin limits total accumulations of metals based upon the metal equivalent concept which has been rejected by the Federal EPA and the State of Ohio. All the states limit yearly cadmium applications (as well as total cadmium applications), the amount being from 0.5 kg/ha to 2.24 kg/ha with Federal EPA having the lowest amount (0.5 kg/ha after 1985) and Wisconsin the highest.

IMPACT OF SLUDGE METAL REGULATIONS

Illinois Sludge Data

Contained in Table 4 are the results of a special sludge survey conducted by the District at its treatment plants and at 24 treatment plants in Illinois which are located outside the District [9]. It can be readily seen that, in general, the plants with large connected populations have higher metal levels. It should also be evident that the sludge produced by these larger plants far exceeds the amounts of all the other plants combined.

Table 5 lists the communities contained in Table 4 but in this table, the allowable tonnages (metric) per hectare are listed for the annual application limits of 1 and 2 kg Cd/ha and the total application limits of 5, 10, and 20 kg Cd/ha. These Cd limitations are representative of the state and federal sludge metal Cd regulations discussed in this paper. Cadmium is generally the limiting constituent for most Illinois municipal sludges and is the element which is the chief concern of those who are considering the regulation of municipal sludges.

In Figure 1 is presented a cumulative frequency graph of the allowable loading for the various annual and total application limits presented in the preceding table. It should be noted that the cumulative frequency is based upon the population of the Illinois plants surveyed rather than the number of plants surveyed.

For the annual application limits of 1 and 2 kg Cd/ha, half of the population surveyed would be limited to applications of less than 10 metric tonnes/ha (4.4 t/acre). This application rate would in many instances not satisfy nitrogen requirements which usually range from 10 to 40 metric tonnes/ha.

For the total application limits of 5, 10, and 15 kg Cd/ha, total application quantities for half of the population studied would be limited to quantities less than 25, 50, and 100 tonnes/ha, respectively. Assuming a 10 tonnes/ha annual loading limit, application sites depending on soil CEC would be limited in time to 2.5 to 10 years. All sludge application would cease after this time.

TABLE 4. THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO
JUNE, 1974

SPECIAL SLUDGE SURVEY OF ILLINOIS COMMUNITIES

COMMUNITY	DATE SAMPLED	SLUDGE CODE*	POPULATION SERVED	CADMIUM	COPPER	MERCURY	NICKEL	LEAD	ZINC	ZN/CD
Naperville	4/22/74									
North	"	SAN	9,000	8	716	1.75	0	167	976	122/1
Central	"	SAN	14,500	10	768	15.6	0	331	1,320	132/1
South	"	PSA	10,000	3	576	1.48	0	58	338	112/1
Lombard	"	PSTAN	36,000	13	681	3.23	170	364	1,570	120/1
West Chicago	"	PCA	11,000	12	390	3.15	116	160	815	68/1
Wheaton	"	PSTAN	60,000	6	1,000	7.19	36	253	1,860	310/1
Salt Creek	"	PSAN	30,000	12	850	7.04	0	607	1,210	100/1
Addison No.#3	"	STAS	20,000	8	1,217	3.79	0	193	1,180	147/1
Glen Ellyn	"	PSTA	26,000	11	963	4.59	0	267	1,350	123/1
Lisle	"	STA	13,000	7	1,194	4.26	0	169	1,430	204/1
Marionbrook	"	STA	25,000	11	744	4.81	0	211	2,010	182/1
Downers Grove	"	PSAN	50,000	47	1,403	8.47	0	570	2,350	50/1
Woodridge	"	STA	6,000	8	790	1.58	0	162	869	109/1

Notes: Metals expressed in milligrams per kilograms dry basis

*Sludge Codes:
SAN = secondary anaerobic
PSA = primary secondary aerobic
PSTAN = primary secondary tertiary anaerobic
PCA = primary w/chemical addition
STA = secondary tertiary aerobic
PSTA = primary secondary tertiary aerobic
PSAN = primary secondary anaerobic
STAS = secondary tertiary aerobic - primary for storm overflow

TABLE 4 (CONT'D)

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO
JUNE, 1974

SPECIAL SLUDGE SURVEY OF ILLINOIS COMMUNITIES*

COMMUNITY**	SAMPLED	SLUDGE CODE*	POPULATION SERVED	CADMIUM	COPPER	MERCURY	NICKEL	LEAD	ZINC	ZN/CD
W-SW	7-17-73 thru	PSAN	2,800,000	210.0	1,381	3.621	348	544	2,708	13/1
Lemont	10-9-73	PSAN	5,080	16.2	433	8.753	37	495	1,212	75/1
East Chgo Hts.	"	PSAN	19,300	4.7	407	1.999	23	57	525	112/1
Northside**	"	UPS	1,418,000	180.0	1,452	3.911	310	513	2,227	12/1
Calumet	"	PSAN	1,163,000	42.0	339	2.359	61	523	2,374	57/1
Hanover Park	"	PSAN	28,800	9.6	748	3.344	59	88	788	82/1
			(5,434,180)							

Notes: Metals expressed in milligrams per kilograms dry basis
*Sludge Codes: PSAN = primary secondary anaerobic
UPS = undigested primary secondary

** Treatment Plants of The Metropolitan Sanitary District of Greater Chicago
*** Includes sludges from Streamwood T.P.

TABLE 5. ANNUAL AND TOTAL CADMIUM LOADING LIMITS FOR ILLINOIS TREATMENT PLANTS

Community	Pop. Served X10^3	Sludge Application Based On Cd Limitation Of*: Annual (kg Cd/ha) 1	2	Lifetime (kg Cd/ha) 5	10	20
		-----metric tons solids/hectare-------				
Lemont**	5.1	61.7	123	308	617	1230
Woodridge	6.0	125	250	625	1250	2500
Naperville(North)	9.0	125	250	625	1250	2500
Naperville(South)	10.0	333	666	1665	3330	6660
West Chicago	11.0	83.3	167	416	832	1670
Lisle	13.0	143	286	715	1430	2860
Naperville(Cen.)	14.5	100	200	500	1000	2000
E. Chicago Hts.**	19.3	213	426	1065	2130	4260
Addison No. 3	20.0	125	250	625	1250	2500
Marionbrook	25.0	90.9	182	454	909	1820
Glen Ellyn	26.0	90.9	182	454	909	1820
Hanover Park**	28.8	104	208	520	1040	2080
Salt Creek	30.0	83.3	167	416	833	1670
Lombard	36.0	76.9	154	384	769	1540
Downers Grove	50.0	21.3	42.6	106	212	426
Wheaton	60.0	167	334	835	1670	3340
Calumet**	1,163.0	23.8	47.6	119	238	476
Northside**	1,418.0	5.6	11.2	28	56	112
West-Southwest**	2,800.0	4.8	9.6	24	48	96

* In some cases nitrogen may be limiting.
** Treatment plants of The Metropolitan Sanitary District of Greater Chicago.

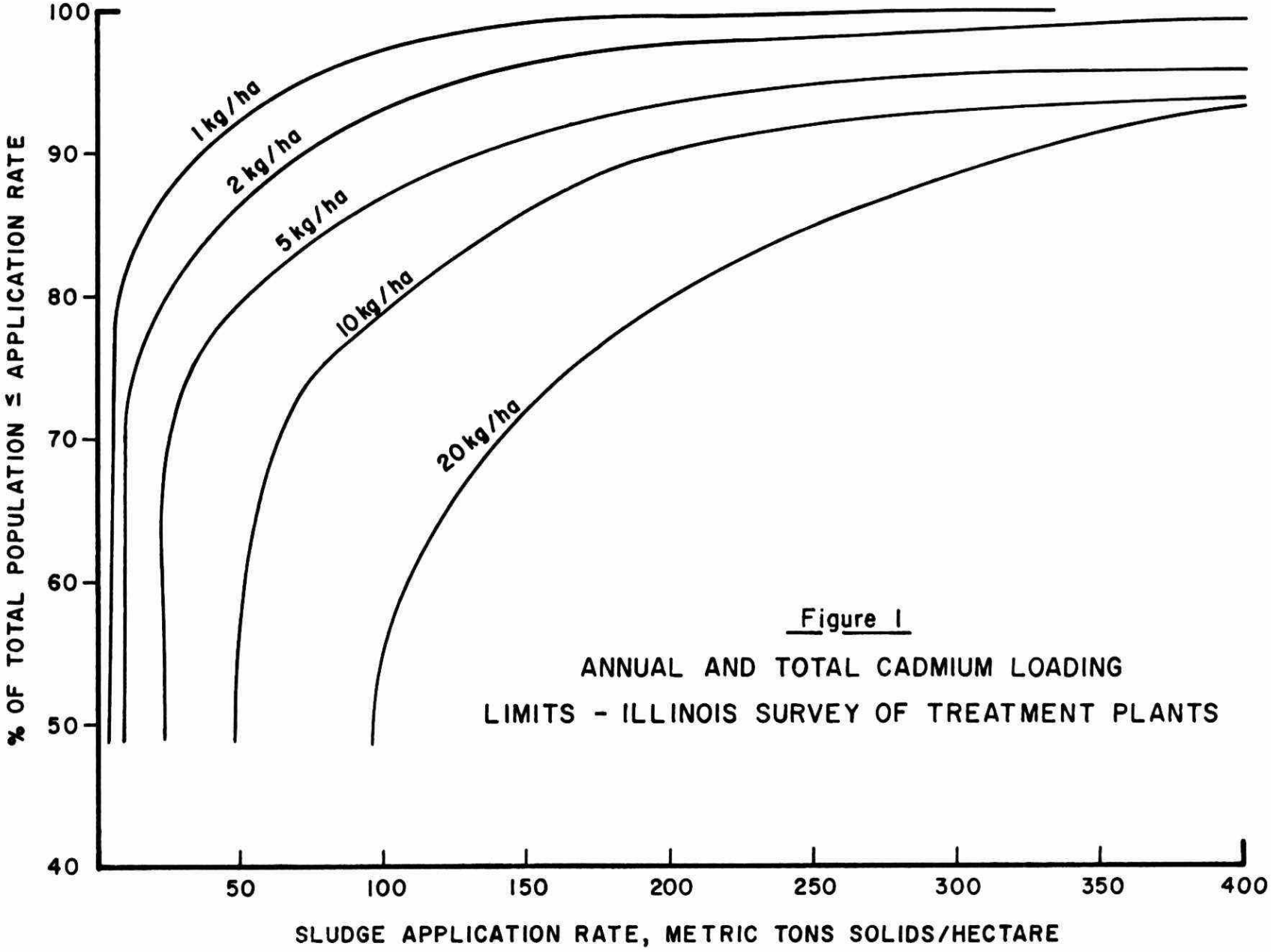

Figure 1

ANNUAL AND TOTAL CADMIUM LOADING

LIMITS - ILLINOIS SURVEY OF TREATMENT PLANTS

Indiana Sludge Data

Contained in Table 6 are the data collected by Sommers et al [10] for various treatment plants in the State of Indiana. In particular, the Cd levels are presented along with the allowable loadings permitted for the annual Cd loadings of 1 and 2 kg/ha and the total application limits of 5, 10, and 20 kg/ha.

In Figure 2 the cumulative frequency of the annual and total allowable loadings presented in Table 6 are given. Cumulative frequency is based upon the population of the plants given in Table 6.

For the annual loading limitations of 1 and 2 kg/ha, sludge application for half of the population studies would be limited to less than 10 tonnes/ha (4.46 t/acre). For total Cd application limits of 5, 10, and 20 kg/ha, 50% of the population in the Indiana survey would be limited to amounts of 10, 30, and 60 tonnes/ha, respectively, depending on soil CEC. For annual application of 10 tonnes/ha, a site life of one to six years would be expected.

Sludge Data From Seven States

The North-Central Regional Agricultural Experiment Station Committee on Utilization and Disposal of Municipal, Industrial and Agricultural Processing Wastes on Land (NC-118) has compiled analyses from select cities in five midwestern states [10]. Table 7 contains the mean Cd levels for this survey and the allowable loadings for these mean values for the annual Cd limits of 1 kg/ha and 2 kg/ha and the total Cd application limits of 5, 10, and 20 kg/ha. For the annual loading limit of 1 kg/ha, loadings of 5 to 13 tonnes/ha are noted. For the 2 kg/ha annual Cd loading limit, the sludge applications range from 10 to 26 tonnes/ha. This annual loading data suggests that the 1 kg/ha loading limit will not allow many plants in the states surveyed to apply sufficient sludge to meet nitrogen requirements, while 2 kg/ha would allow 10 to 26 tonnes/ha and, therefore, at least some of these plants could apply amounts consistent with crop nitrogen requirements. Total application limits for a cadmium limit of 5 kg/ha range from 25 to 65 tonnes/ha, for a cadmium limit of 10 kg/ha, range from 50 to 130 tonnes/ha and for a 20 kg/ha Cd limit range from 101 to 260 tonnes/ha.

TABLE 6. ALLOWABLE ANNUAL AND LIFETIME SLUDGE APPLICATION ON CROPLAND FOR INDIANA SLUDGES [10]

City	Pop, X10^3	Mean Cd of Sludge	Sludge Application Based On Cd Limitation Of*: Annual (kg Cd/ha) 1	2	Lifetime (kg Cd/ha) 5	10	20
		mg/kg solids	------metric tons solids/hectare-----				
Tepton	5.3	11	91	182	454	910	1820
Lafayette	5.3	125	8	16	40	80	160
Nobelsville	7.5	93.5	11	21	53	107	214
Greencastle	9	48	21	42	104	208	417
Lebanon	10	53	19	38	94	189	377
Crawfordville	13.2	19	53	105	263	526	1050
Peru	15	136	7.3	15	37	73	147
Logansport	20	503	2.0	4	9.9	20	40
Kokomo	65	846	1.2	2.4	5.9	12	24
Anderson	76	210	4.8	9.5	24	48	95

* In some cases nitrogen may be limiting.

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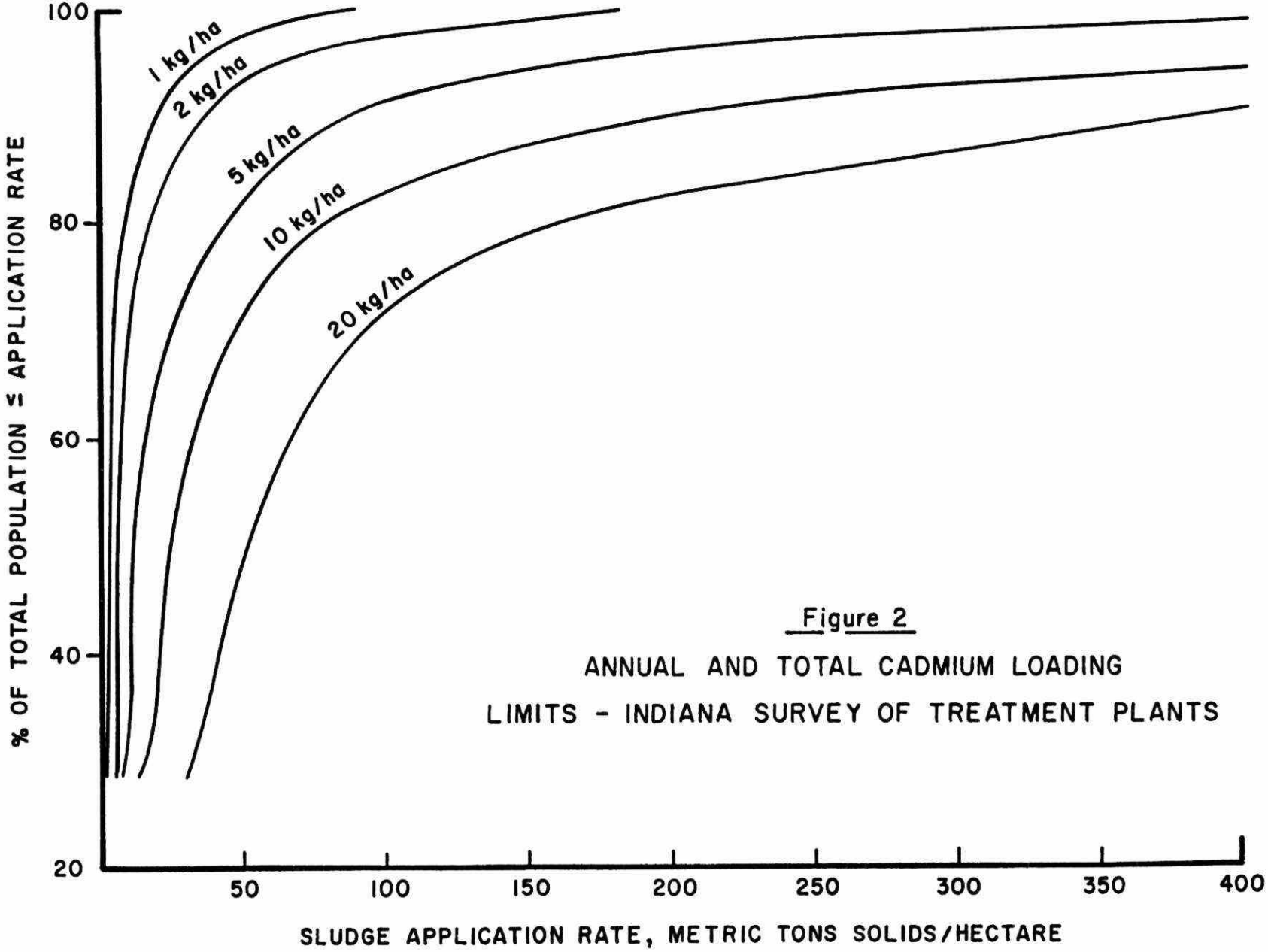

Figure 2

ANNUAL AND TOTAL CADMIUM LOADING

LIMITS - INDIANA SURVEY OF TREATMENT PLANTS

TABLE 7. ALLOWABLE ANNUAL AND LIFETIME SLUDGE APPLICATION RATE NC-118 SURVEY [10]

State	Mean Cd of Sludge	Sludge Application Based On Cd Limitation Of*: 1 kg/ha/yr.	2 kg/ha/yr.	Total in Lifetime (kg/ha) 5	10	20
	mg/kg	metric tons/ha (dry basis)				
Wisc.	77	13	26	65	130	260
Ind.	163	6	12	31	61	122
Minn.	131	7.6	15	38	76	153
Mich.	163	6	12	31	61	122
Ohio	198	5	10	25	50	101

* In some cases nitrogen may be limiting.

This indicates for a 10 tonne/ha loading rate, site life would range from 2.5 to 26 years.

Summary

The sludge metal data presented in the last three sections clearly show that the proposed cadmium limitations would impose severe restrictions on many municipalities. Annual sludge loadings for many plants will be limited to rates less than that needed for crop nitrogen requirements. Under such conditions, chemical fertilizer would have to be supplemented.

If the municipality is using the sludge for its own farming operation, this is an added expense which may make land application economically unattractive. If the sludge is being utilized by local farmers, it is highly unlikely that they will continue to use the sludge if they must supplement it with chemical fertilizer.

Total metal application limitations for the states studied resulted in site lives of 2.5 to 26 years. Such site lives result in the need to continuously move to new land tracts for municipalities running their own farming operation. The economic implications here are obvious. For local farmers who may use the sludge, such site life limitations will usually mean that they will not continue such use. It simply is not worthwhile for many farmers to invest the time and possibly in added equipment costs to utilize a product for two growing seasons.

SLUDGE METAL UPTAKE RESEARCH

The impact of the proposed or existing regulations or guidelines has been discussed. In this chapter, we will discuss how the proposed regulations compare with studies where municipal sewage sludge was applied to land and the uptake of metals by growing plants was studied.

Hanover Park Experimental Corn Plots

A most extensive demonstration study was undertaken in 1968 by the District at its Hanover Park treatment plant.

In 1968, a 7-acre field at the Hanover Park Water Reclamation Plant was selected for development of experimental corn plots for furrow

irrigation, the topsoil was stripped, the sub-soil graded to desired slope, and the topsoil was replaced. The soil is a disturbed Drummer silty clay loam with poor natural drainage. The original experimental design was a randomized block with five replications having grades of 0.5, 1.5, and 2.5% confounded in the replications.

Metals

Soil samples were taken in spring and were composites of 20 cores, 0 to 6 inches deep.

Corn grain analysis for trace metal content began with the 1973 corn crop. Grain subsamples were taken during corn yield determinations.

Each spring the plots were plowed and harrowed. Ridges and furrows were formed parallel to field slope. Sludge was applied from gated irrigation pipes at the upper end of the plots and allowed to flow down the furrows.

The plots have been fertilized with sludge very year beginning in 1968. Most of the sludge applied came directly from heated anaerobic digesters at the Hanover Park Water Reclamation Plant. In a few instances, lagooned digested sludge was also applied. The average analyses of the digested sludge applied are presented in Table 8.

Effect of sludge application on soil

Analyses of the soil samples in 1970, 1973, and 1975 are presented in Table 9. The control plot showed a depletion of some major nutrients and organic carbon over this time period. No nitrogen or phosphorus fertilizer has been applied to the control plots. Potash fertilizer was applied to all plots in 1968 and 1972 to 1975. There was no influence on soil pH from the sludge application.

The 1975 soil analysis showed that Zn, Cd, Fe, available P, $NO_2 + NO_3 - N$, organic carbon, and 1/3 bar water holding capacity all increased with the increase in the levels of applied sludge. The level of Ni and cation exchange capacity (CEC) indicates that if higher levels of sludge application were to be used the Ni and CEC level would not increase any further. The soil concentration of Cu, Pb, and Cr increased with increased sludge application.

TABLE 8. AVERAGE CHEMICAL CONCENTRATION OF THE LIQUID DIGESTED SLUDGE APPLIED AT THE HANOVER PARK PLOTS FROM 1968 TO 1975 AND AT THE FULTON COUNTY SITE IN 1975.

Constituent	Hanover Park	Fulton Co.
Kjeldahl N	4.8	5.7
NH_3-N	2.8	2.5
P - Total	2.0	3.8
K	0.40	0.39
Ca	3.4	2.8
Mg	1.3	1.2
Fe	2.0	4.7
Zn	0.075	0.39
Mn	0.048	0.038
Ni	0.022	0.042
Cu	0.070	0.18
Na	0.46	0.23
Pb	0.028	0.093
Cr	0.026	0.38
Cd	0.0056	0.030
Hg (µg/g)	--	6.95

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TABLE 9

Chemical and physical properties of a disturbed Drummer silty clay loam collected in 1970, 1973 and 1975 from the Hanover Park experimental corn plots. These plots have received liquid sludge from 1968 through 1975.

Parameter	1970			1973			1975		
	Sludge Applied to Date (T/A)								
	0	15	25	0	37	62	0	52	91
pH	7.9	7.7	7.7	7.3	7.1	7.1	7.8	7.5	7.6
CEC meq/100g	33.4	34.0	32.2	33.9	33.7	33.3	31.4	34.5	32.3
1/3 bar H_2O %	38.0	38.0	36.8	32.2	33.1	32.2	32.0	34.7	33.8
C-organic %	3.08	3.21	3.15	2.61	3.37	3.33	2.66	3.35	3.01
P-available µg/g	N.A.*	N.A.	N.A.	9.8	51.5	79.8	31.3	102.9	113.9
Exchangeable									
K µg/g	138	158	153	126	149	126	106	122	117
Na µg/g	95	131	117	25	30	44	22	84	78
Ca µg/g	5440	5660	5530	5140	6300	5650	4300	4680	4590
Mg µg/g	1520	1600	1600	1660	1700	1690	1060	1100	1060
0.1 N HCl Extractable									
Fe µg/g	813	827	835	301	339	346	247	409	412
Mn µg/g	253	281	290	198	200	195	211	222	235
Zn µg/g	30.5	39.0	37.5	24.4	23.4	27.6	22.9	50.0	51.7
Cd µg/g	0.7	0.7	0.5	0.68	0.58	0.61	0.39	0.49	0.50
Cu µg/g	18.3	66.6	33.8	6.72	13.3	15.8	9.3	23.2	30.2
Cr µg/g	1.7	2.30	5.2	0.93	1.26	1.47	0.42	1.02	1.46
Ni µg/g	11.3	10.9	10.9	8.60	9.11	8.93	6.78	8.15	7.39
Pb µg/g	16.2	11.8	13.3	8.25	9.21	9.68	9.1	12.0	13.9

*NA = No Analysis

Effect of sludge application on corn

Metal uptake in the grain was determined in the 1973 and 1975 crops. These data are presented in Table 10.

The only significant increases in metal content in 1973 were with K and Ca. These increases occurred with the 52 tons/acre sludge application, and the reasons for these increases are not apparent. The 1975 grain crop showed significant increases in Zn, Cd, Cu, and Fe content with the addition of sludge. The Fe increase was linear in behavior for the sludge application rates used, while the Cu response appears to be approaching a maximum.

The Cd concentration of the grain grown in 1975 on the 85 and 110 tons/acre total sludge applications were 0.091 and 0.096 µg/g, respectively.

A survey conducted by Pietz, Peterson, Lue-Hing, and Welch [11] on 15 corn fields located throughout Illinois, where all fields were fertilized with inorganic fertilizer, yielded a mean Cd concentration of 0.038 µg/g and a range of 0.001 to 0.294 µg/g in the grain. A summary of this survey is presented in Table 11. The concentrations of Zn, Cu, Cd, and Fe at the Hanover Park farm were all within the range reported by Pietz et al [11].

The corn yields in 1973 were 29, 78, and 99 bushels per acre for the 0, 52, and 79 tons/acre (accumulative) of sludge applications, respectively. In 1975, the corn yields were 49, 102, and 82 bushels per acre for 0, 85, and 110 tons/acre of sludge applications, respectively.

Through 1975, 13.8 kg/ha of Cd have been applied on the maximum sludge application plot. For the soil CEC of the Hanover Park plots, this amount is below the maximum lifetime amount specified in the Federal Technical Bulletin, the proposed solid waste regulations, and the guidelines for the States of Illinois, Indiana, Ohio, and Wisconsin. However, average yearly Cd applications have been approximately 1.7 kg/ha which exceeds the maximum yearly specified by the proposed solid waste regulations.

THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO

TABLE 10

Chemical concentration of 1973 and 1975 corn grain grown at the Hanover Park experimental corn plots which have received liquid sludge from 1968 through 1975.

Sludge Applied to Date	Zn	Cd	Cu	Cr	Fe	Ni	Pb	K	Na	Ca	Mg	Mn
T/A	µg/g dry basis											
1973												
0	25.0	<0.5	1.74	0.77	39.2	<0.5	0.81	3030	26.2	57.9	1330	5.07
52	25.8	<0.5	2.01	0.76	34.4	<0.5	0.83	3600	27.2	70.6	1340	5.51
79	23.8	<0.5	1.70	0.71	36.9	<0.5	0.79	3158	32.1	55.0	1240	5.65
1975												
0	18.2*	0.067**	1.81**	0.076	23.6**	0.63	0.54	3260	9.71	61.4	1070	5.70
85	25.8	0.091	2.32	0.058	29.8	0.43	0.53	3490	2.78	57.8	1140	6.52
110	25.8	0.096	2.29	0.067	30.3	0.48	0.51	3380	3.39	54.2	1160	6.52

*Values in a column are significant at the 0.05 level of probability for that year.
**Values in a column are significant at the 0.01 level of probability for that year.

TABLE 11. ELEMENTAL ANALYSIS OF CORN GRAIN FROM 15 LOCATIONS IN ILLINOIS [11] (243 Samples)

Element	Mean ± SD*	Range	Coefficient of Variation
	..... µg/g		..... % .....
Ca	50.6 ± 8.4	33.3 - 98.5	16.6
Fe	20.3 ± 9.4	10.4 - 84.0	42.2
K	2,970 ± 954	1,930 - 4,000	32.1
Mg	1,080 ± 105	617 - 1,480	9.77
Mn	5.60 ± 1.01	2.00 - 9.26	18.1
Na	7.80 ± 5.44	1.24 - 35.5	69.7
Cd	0.038 ± 0.030	0.001 - 0.294	81.3
Cr	0.087 ± 0.059	0.002 - 0.429	68.0
Cu	2.62 ± 0.88	1.32 - 6.31	33.5
Ni	0.87 ± 0.34	0.17 - 2.50	39.6
Pb	0.168 ± 0.065	0.033 - 0.519	38.5
Zn	19.6 ± 3.2	13.0 - 32.6	16.6

* Standard deviation of the sample

Dayton, Ohio Sewage Treatment Plant Farm

At Dayton, Ohio, the sewage sludge has been spread on Warsaw silt loam for 35 years. The annual sludge application rate has been calculated at 28 metric tonnes/ha (12.5 tons/acre). A study of the trace metals in the corn grown on this land was conducted by Kirkham [12] in 1973. She reported the total concentration of metals in the 0 to 30 cm depth of soil was increased by the following factors: Cd, 35; Cu, 16.5; Ni, 2; Pb, 16.5; and Zn, 13. Even with these large increases in the metals present in the soil, these metals did not accumulate appreciably in the corn plants when compared to unsludged corn plants. For example, the Cd content of corn grains was 0.9 and 0.8 µg/g dry wt. for sludge-grown and control corn, respectively. The Dayton, Ohio, sludge contained from 800 to 830 mg Cd/kg, 4,100 to 6,020 mg Cu/kg, 400 mg Ni/kg, 4,000 to 6,940 mg Pb/kg, and 8,390 to 10,500 mg Zn/kg dry wt. basis. This calculates to a total 35-year per hectare application of approximately 780 kg Cd, 4,020 kg Cu, 390 kg Ni, 3,800 kg Pb, and 8,200 kg Zn.

These loadings for Cu, Ni, Pb, and Zn, as reported by Kirkham are very much higher than those of the Federal government and the States of Wisconsin, Indiana, Ohio, and Illinois. However, it is clear that the Cd uptake in the sludge-amended corn grain is very small. Using the Wisconsin guidelines where the total sludge application is limited by the lifetime maximum of 20 lb Cd/acre (22.4 kg/ha) the highest total of any regulation discussed here, the Dayton sludge which contained 0.8 kg Cd/metric tonne of solids would be limited to a one year lifetime single application of 28 metric tonnes/ha (12.5 tons/acre).

Kirkham estimated the total sludge application at Dayton, Ohio to be 980 metric tonnes/ha over the 35-year period on record.

University of Illinois Experimental Field Plots - Soybeans

Except for the 1975 data, most of the results reported in Table 12 were presented previously by Hinesly et al [13]. By regression analyses, they concluded that sludge-borne Cd incorporated into soil just prior to planting soybeans was more efficiently assimilated than sludge-borne Cd applied in years previous to the crop year. Results of

TABLE 12. MEAN DRY WEIGHT Cd CONTENTS OF SOIL SAMPLES FROM 0- to 6-INCH DEPTHS AND SOYBEAN SAMPLES COLLECTED FROM BLOUNT SILT LOAM PLOTS [13]

YEAR	Cumm. Solids mt/ha	SLUDGE APPLICATION RATES (inches) 0	1/4	1/2	1	LSD
		Cd µg/g Soil 0.1 N HCl Extractable				
1969	43					
1970	102					
1971	237	<.10	2.94	8.11	13.33	2.29**
1972	242	0.19	3.63	9.53	15.24	1.43**
1973	255	0.16	3.86	8.51	13.66	1.38**
1974(A)	314	0.20	4.03	8.14	14.69	4.53**
1974(B)	255	0.15	4.43	8.74	14.13	4.45**
		SOYBEANS				
				Soil pH		Cumm. Cd kg/ha	
1970		.06	.32	.54	5.7	1.02	34.7	0.30**
1971		.27	.41	.90	5.4	1.55	58.5	0.30**
1972		.29	.49	.94	5.2	3.00	59.4	0.93**
1973		.18	.31	.55	5.8	0.75	62.0	0.13**
1974(A)		.31	.31	.57	6.0	0.92	77.6	0.39**
1974(B)		.13	.23	.35	6.1	0.35	62.0	0.15*
1975(A)		.07	.34	.72	6.0	1.69	89.2	0.31**
1975(B)		.12	.18	.34	6.3	0.46	62.0	0.29**

A--Sludge applications were resumed after harvest in 1973.
B--Sludge applications were suspended following one application in 1972.
*Significant at the 0.05 level of probability.
**Significant at the 0.01 level of prabability.

their analyses suggested that if annual sludge applications were terminated, Cd contents in plant tissues would be drastically reduced. To further test the hypothesis, annual sludge applications were continued on one-half and terminated on the other half of split plots, beginning in 1973. Another reason for making the split was because soybeans growing on maximum sludge-treated plots had suffered from P toxicity in 1972. The P toxicity was not observed in 1973, when sludge was not applied to any plots after two applications in the early part of the 1972 growing season until after harvesting operations in 1973. In 1974, on split-plots where maximum sludge applications were resumed in 1973, soybeans had a Cd content of 0.92 µg/g as compared to 0.35 µg/g in soybeans grown on plots where no further applications were made. Also, it may be noted that where sludge applications were terminated, Cd contents of soybeans from plots previously treated with 1/4-maximum sludge applications were not significantly different from Cd contents in soybeans from control plots. In 1975, Cd contents of soybeans from plots where sludge applications were terminated were similar to those of soybeans in 1974. But in 1975, Cd contents in beans from previously treated 1/4-maximum and 1/2-maximum treated plots were not significantly different from contents of soybeans from control plots. Soybeans growing on maximum sludge-treated plots in 1975 where application had been resumed, suffered from P toxicity again. Cadmium contents were highest in 1972 and 1975 in soybeans harvested from maximum sludge-treated plots where plant growth was adversely affected by P toxicity. Thus, it is concluded that Cd contents in soybeans will decrease with time after sludge applications have been terminated and that Cd contents will be increased in plants subjected to conditions adversely affecting growth.

University of Illinois Experimental Field Plots - Corn

Except for the 1975 results, all of the data presented in Table 13 were previously reported by Hinesly et al [14]. Regressing Cd contents of corn grain on annual and accumulative sludge-borne Cd applications, they concluded that application just prior to planting the crop was the main determinant of Cd levels in corn grain. However, even in the absence of results from regression analyses, an examination of the

TABLE 13. MEAN DRY WEIGHT Cd CONTENTS OF SOIL SAMPLES FROM 0- to 6-INCH DEPTHS AND CORN GRAIN SAMPLES COLLECTED FROM BLOUNT SILT LOAM PLOTS [14].

YEAR	SLUDGE APPLICATION RATES (inches) 0	1/4	1/2	1	LSD
	Cd µg/g				
	Soil 0.1 N HCl Extractable				
1971	<0.25	1.3	3.6	6.8	4.0**
1972	0.27	3.1	4.7	12.1	3.3**
1973	0.29	3.3	6.7	12.9	3.6**
1974	0.58	3.8	7.3	16.4	4.9**

	Cumm. Solids mt/ha	CORN GRAIN			Soil pH		Cumm. Cd kg/ha	
1970	152.5	0.30	0.60	0.79	4.9	1.00	48	0.20**
1971	280.9	0.14	0.70	0.65	5.2	0.92	77	0.40**
1972	306.5	0.14	0.45	0.83	5.0	1.10	81	0.52**
1973	368.6	0.08	0.15	0.35	5.3	0.61	88	0.06**
1974	417.4	0.09	0.18	0.40	6.2	0.81	101	0.22**
1975	449.9	0.06	0.17	0.28	6.6	0.51	108	0.08**

A--Sludge applications were resumed after harvest in 1973.
**Significant at the 0.01 level of probability.

data presented in Table 13 shows that Cd levels in corn grain varied with the amount of sludge-borne Cd applied by furrow irrigation during the previous growing season and incorporated just prior to the crop year of interest. On a per unit basis of annually applied sludge-borne Cd, levels of the metal in corn grain remained fairly constant regardless of amounts incorporated by spring plowing in years previous to a particular crop year. These data suggest that if Cd levels in grain are within acceptable concentrations for a particular annual loading rate of sludge-borne Cd, the situation will not change with accumulative years of sludge applications.

From both the soybean and corn data presented in Tables 12 and 13, it appears that availability of Cd is considerably more important in determining levels in plant tissues than soil pH. Availability of sludge-borne Cd for assimilation by plants is greatest immediately after incorporation into soils and then decreases with time.

The Cadmium Question

The central idea behind all the regulations discussed in this paper is the protection of the American diet against increase of cadmium. It is fairly well established that the American diet contains about 50 to 70 µg/day of Cd [15]. Although the data on long-term low-level exposure to these levels is not conclusive, there is a belief on the part of many that levels much above that contained in the American diet could pose the risk of increased cases of kidney failure.

Cadmium in the diet comes from a variety of sources including meat, vegetables, and grains. Generally, however, the chief concern centers around increases of diet Cd due to sludge fertilization of leafy vegetables, leafy vegetables being good accumulators of metals contained in soil naturally or due to sludge [15]. The scenario advanced by those proposing regulations on sludge application to crops is that an individual grows all of his own vegetables on a plot using sludge for fertilization, and this individual eats only these vegetables and eats them for say 50 years.

In reality, the chances for such an occurrence are miniscule; and, indeed, there is no direct evidence to prove that a health problem

would develop even if it did. Nevertheless, it becomes the responsibility of those using sludge as a fertilizer to prove that a problem would not develop under such conditions rather than of the regulatory authority to prove that there will be.

The regulatory authorities have, it appears, adopted the most conservative approach possible. They have selected levels of sludge application where no increase in diet cadmium could occur. As shown in this paper, cadmium additions above those proposed by the Federal government have resulted in either moderate or no increase in the cadmium level of the crop grown; while in some cases increase occurred but not above that found in crops grown with chemical fertilizers.

All the regulations appear to be protective of the scenario described above without any attempt to use the knowledge developed by many researchers. Today there are many facts which are known which can be used to judiciously choose sludge application schemes which will have minimal or no health risk.

For example, it is well known that soybeans and corn are not significant accumulators of Cd. This is shown by the data presented in this paper from the Hanover Park studies and those of Hinesly [13, 14] and Kirkham [12]. In addition, the work of Hinesly has shown that yearly sludge application is the single most important factor in crop metal uptake. Studies by Hinesly [16] and a literature survey by Pahren [15] have shown that the muscle tissue of animals is not affected by increases of diet Cd due to feeding of sludge-amended plants.

It seems clear that there is no need for sludge metal regulations for projects raising crops for animal feed.

In general, except for those crops shown to be accumulators of metals such as lettuce, spinach, etc., there is no need to regulate sludge metal application. Restricting annual applications of sludge to crop nitrogen requirements will insure that little, if any, increases in crop metal levels will occur.

It is interesting to note that at least some individuals in the U.S. EPA, namely, Pahren et al [15] have indicated that increases in daily diet Cd intakes to 110 µg are possible without health problems. This represented about 2-fold increase over the current level estimated by Pahren et al.

It seems clear that a policy must be adopted by the regulatory authorities which balances the health risks versus the societal need to dispose of sludge. The current trend toward regulations for the worst possible case coupled with the attitude that those using sludge as a fertilizer must prove that no problem exists must be reversed. There is sufficient information available to regulators to allow selective regulation of sludge to land and allow higher application rates in situations where the health risk is minimal.

Alternatives to Empirical Sludge Equations - Industrial Waste Control

A very effective way to reduce the level of metals contained in municipal sewage sludges is to limit the industrial input of metals at the source, namely, at the point where industry discharges into the sewer system. While industrial waste control has been shown to be effective, it must be emphasized here that metals including cadmium and mercury will always be present in sewage sludges as a result of their natural content in food and human wastes, and from surface runoff, etc.

A successful case in point is the experience of the District where an industrial waste control ordinance has been in effect since 1969. To evaluated the effects of this ordinance, the metal content of anaerobically digested sludges from the Calumet plant which were placed in storage lagoons before 1969 were compared with sludges from this same plant through the summer of 1974, as shown in Table 14. It is clear from the data that the metal content of the sludge was lower after passage of the ordinance than before. The concentrations of metals of greatest environmental concern (nickel, copper, lead, and cadmium) were reduced in the digested sludges by 92, 81, 73, and 72%, respectively, during the period from 1969 to 1974. Data for 1976 are similar to those for 1974, which indicates that industrial waste control has reached its limits of effectiveness for this plant with respect to sludge metals levels.

Although an industrial waste control program can effect substantial reductions in the metal content of sludge in industrial areas, it must be emphasized that each sewage treatment plant or the area served by one has an indigenous concentration for all metals which may not be further reduced by more stringent industrial pretreatment.

TABLE 14. EFFECT OF INDUSTRIAL WASTE CONTROL ORDINANCE ON METALS CONTENT OF THE CALUMET SEWAGE TREATMENT PLANT'S SLUDGE

Metal	Max. Limit By Ordinance	Sludge Source: Lagoons Before 1969*	Sludge Source: Anaerobic digester 1972**	Sludge Source: Anaerobic digester 1974***	Metal Reduction Before 1969/1974: Ratio	Metal Reduction Before 1969/1974: Percentage
	mg/L	.....µg/g dry weight basis.....				
Cd	2.0	190	100	54	3.51	72
Cr (Tot.)	25.0	2100	1100	790	2.66	62
Cu	3.0	1500	900	282	5.32	81
Fe	50.0	53700	36800	24200	2.22	55
Hg	0.0005	3.3	3.0	2.15	1.53	34
Ni	10.0	1000	200	77	12.99	92
Pb	0.5	1800	1800	486	3.70	73
Zn	15.0	5500	3500	2800	1.96	49

* Mean of 10 samples from the Calumet Sewage Treatment Plant sludge lagoon

** Mean of 22 samples from June to October 1972

*** Mean of 6 samples from the Calumet Sewage Treatment Plant anaerobic digesters from June to October 1974

A successful industrial pretreatment program implies the existence of effective monitoring and enforcement procedures. In view of the political ramifications of these procedures, the effectiveness of an industrial pretreatment program cannot be generalized from one area to another until such time that the commitment becomes national.

CONCLUSIONS

The combination of population growth and the fact that the majority of the population live in metropolitan areas has created large wastewater sludge problems. On top of this is the urgency to clean the nation's waters which adds to the volume of sludge produced. With these conditions and the concern for a safe food supply, the thought of applying sewage sludge to cropland causes some persons great concern. This precipitated many regulations regarding the proper usage of sewage sludge.

We have discussed the Federal guidelines as well as the guidelines for the States of Illinois, Indiana, Wisconsin, and Ohio. By and large, they all closely follow the Federal policy which limits the amount of Pb, Zn, Cu, Ni, and Cd that can be applied to cropland.

Research by the District and the University of Illinois clearly indicate that crop restrictions would be a more realistic approach to the protection of foods, in particular, the limitation of leafy vegetable production on sludge fertilized land. Field crops can be safely fertilized with sewage sludge if the application rate is based on the nitrogen requirements of the plant.

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COST ESTIMATION TECHNIQUES FOR SEWAGE SLUDGE DISPOSAL

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INTRODUCTION

Many different technically feasible solutions exist for any particular problem. We need to have tools available to screen out those technically feasible ideas that are economic disasters. Thus, decision-makers, engineers and designers need some economic metre sticks that can be applied periodically through the development of any project to ensure that the project is still going along the right way.

Near the beginning of the project the economic metre sticks are usually very crude and only help us to identify the general areas where we should be directing our attention. The errors in such metre sticks could be as large as +100%, -50%. Despite such inaccuracies these measures are useful.

Later in the project, more accurate metre sticks are available and need to be applied. At this stage we are usually trying to identify the top candidates. Detailed technical and economic analysis can then be done on these. The metre sticks used here will often have $\pm$ 30% accuracy.

Even later a detailed economic analysis will be done, such as when a contract bid is being prepared, where an accuracy of $\pm$ 5 to 10% is expected.

Although we have identified three different phases of decision-making when successively more accurate economic metre sticks are used, in practice there is a range of metre sticks and occasions when these metre sticks are used. The general development of a project, the type of economic screening done and the decision-making procedure are illustrated in Figure 1. In this paper we explore the methods that are available for

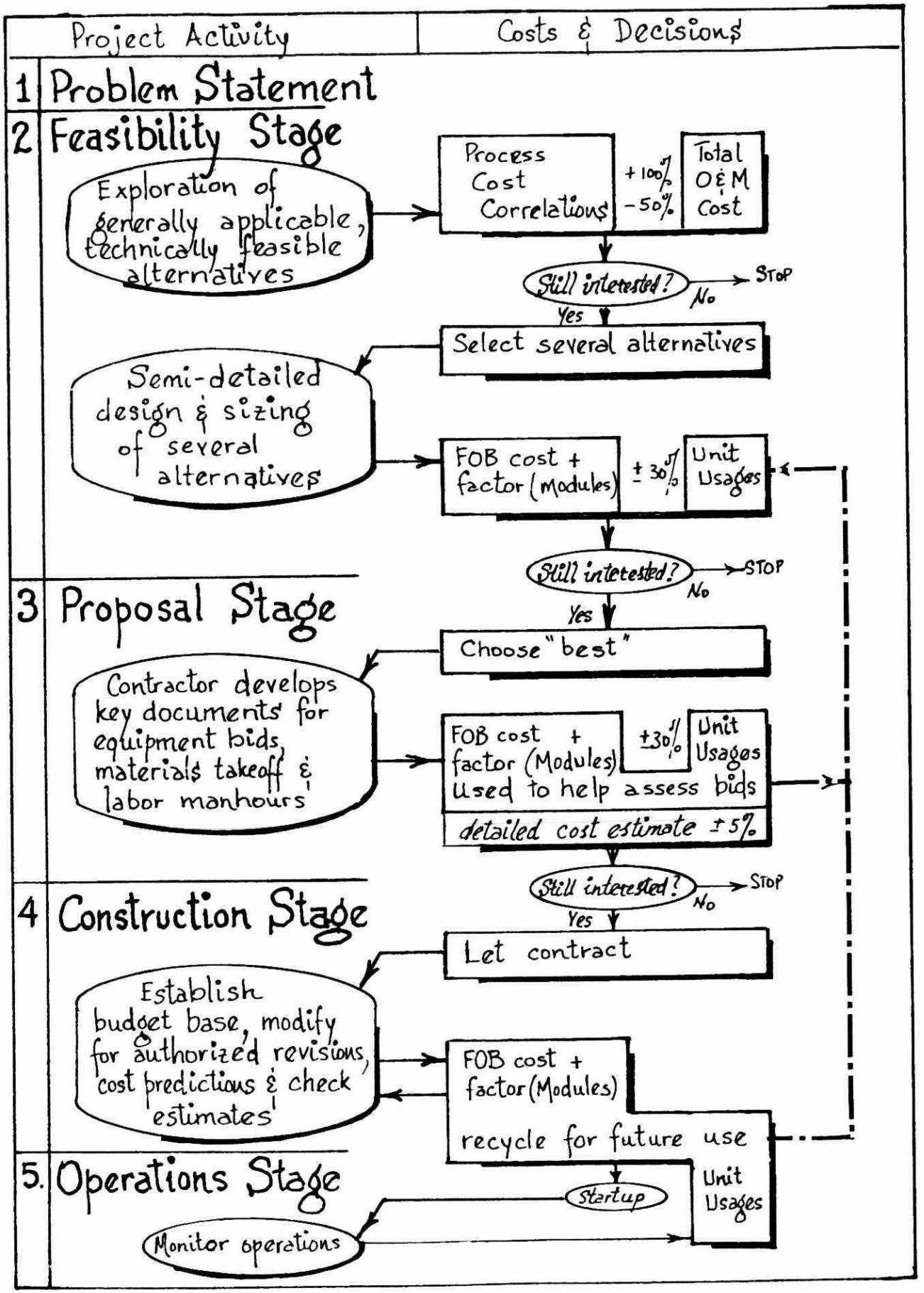

FIGURE 1. THE ROLE OF COST IN PROJECT DEVELOPMENT

the first two economic metre sticks: that with accuracy + 100%, -50% and that with accuracy ±30%. The two major economic metre sticks are the annual operating cost and the initial capital investment. The actual decision-making criterion is the annual operating cost per unit of waste processed. That is, we want to select the technical alternative with the minimum annual operating cost per unit of waste processed. A typical annual operating cost is shown in Table 1. The cost components include the operating labor, chemicals, utilities, maintenance, depreciation, taxes and insurance, ultimate disposal, analytical services and general overheads. In general, the operating cost components related to the capital investment tend to dominate the operating cost. These cost components include maintenance, depreciation, and taxes and insurance.

The second economic metre stick is the initial capital investment. This tells us how much it costs to construct the plant. As noted above it is also usually a significant component of the operating cost.

Consider now each of these two criteria in turn.

CAPITAL COST ESTIMATION

The capital cost is the amount of money spent to build the plant. This includes:

1. the cost of purchasing and installing all the necessary equipment into such a condition that it is operable (includes the FOB (free on board) the supplier cost of all fabricated equipment; delivery costs, sales taxes and duties; installed concrete; structural steel; electrical hookups; instruments; piping and insulation; painting and all installation materials and labor);
2. the contractor's fees;
3. the engineering expense to design and prepare the drawings and for all home office expenses related to the project;
4. the field expense to supervise construction and for the construction facilities and security thereof;
5. the legal fees related to the project and its administration and financing.

TABLE 1. A TYPICAL ANNUAL COST FOR A WASTE TREATMENT FACILITY.

COST ITEM	ANNUAL COST, $/a
Raw materials (chemicals)	8 500
Utilities	
Electricity, Steam, Fuel, Cooling water	5 400
Operating Labor	8 000
Supervision	1 200
Maintenance	
Labor, Materials	2 000
Overhead	6 000
Analytical services	100
Depreciation, Capital charges	25 000
Taxes	1 000
Insurance	100
Disposal	-
Byproducts (credit)	-
	57 900

Other items that need to be accounted for, but not necessarily in the above cost, are:

6. the buildings;
7. the land;
8. the site preparation and yard work;
9. the interest on the capital borrowed during the construction stage of the project;
10. the start up costs;
11. a contingency to allow for unexpected delays, strikes or difficulties encountered during the construction; (Naturally a contingency factor exists only for estimates of uncompleted projects. Once a plant has been constructed whatever contingency was necessary would be allocated to the source of the expense.)
12. special architectural requirements;
13. special land needs such as blasting, piling or drainage.

The working capital is the money required to purchase the initial supply of on-hand chemicals, solvents, catalysts or packings. Because this money is usually completely recoverable when the plant becomes obsolete and is shut down, this working capital is not considered to be fixed capital investment. However, because the total initial amount of capital required is the fixed capital investment plus the working capital, for environmentally related projects funded by debentures, the working capital should be included. When one is talking about capital costs it is important to know which of the above components are included in the cost.

Another consideration is whether the facility is to be a grass-roots or a battery limits installation. A grass-roots (GR) installation refers to a new facility built where no previous plant existed. The cost will, therefore, have to account for the land, site preparation and the host of other expenses incurred because the complete site has to be developed. A battery limits (BL) installation refers to the construction of a facility on an already-prepared and serviced site. This could occur if the waste treatment facilities are to be added to an existing industrial site or, for example, if a sludge dewatering unit

is being added to an existing waste treatment facility. Table 2 summarizes the differences between a BL and a GR contract, as viewed by a large contractor in the process industry.

In this paper, we consider only battery limits costs. That is, we assume that this is an add-on feature to an existing process on an already developed site. In addition we exclude the costs of buildings, land, site preparation, startup, and architectural requirements. Nevertheless, we will include interest during the constructive stage, contingency and a separate allowance for working capital. A summary of the costs pertinent to this paper are given in Table 3. Here we note four special costs pertinent to the environmental battery limits capital costs: the total physical plant cost (no. 5), the contract cost (no. 7), the fixed capital investment (no. 11a), and the bonded capital cost (no. 14). Also given in this table are the factors that show reasonable relationships between these different costs. These relationships will be discussed later. How can we estimate the total bonded capital cost for alternative sludge dewatering units?

Cost Correlations for Complete Packages

For inaccurate but rapid estimates of the capital cost we can look up cost correlations that relate the capital cost to the general plant throughput for an average waste and conditions. The term average is not often defined. For sludge dewatering the plant throughput might refer to the feed to the complete waste treatment plant, i.e., to the pretreatment degritting unit, the feed to the sludge dewatering unit or the amount of exit dewatered sludge.

Usually the cost cited is the "contract cost" (see Table 3), that excludes interest, working capital, contingency, legal, field expense and engineering expense. Sometimes the contract cost is multiplied by 1.25 to 1.35. See for example Culp et al (1974), Adams and Eckenfelder (1975), Smith (1968), and Weber (1970) to obtain a bonded cost. These factors are consistent with those given in Table 3. All costs must be identified with some stated date or time. All data cited here are for December 1975 when the Marshall and Swift* Inflation index was 451 or for

*Marshall and Swift is the same index as Marshall and Stevens.

TABLE 2. A BATTERY LIMITS COST VERSUS OTHER TYPES OF COSTS

includes the cost of	excludes the cost of
-all process equipment within the battery limits, normal within BL in process surge tanks	1. land, site preparation, fencing, access roads and paving, loading and unloading facilities.
-all material and labor to connect and make operable this process equipment incl. control room, buildings within the BL	2. off-site utilities and piping to/from the BL from such services
-indirect field expense, engineering home office expense, administration of the contract	3. bulk storage of feed, products and byproducts
-contractor's and subcontractor's fees	4. support facilities such as the administration building, laboratory, cafeteria, gate house, maintenance shops, fire fighting equipment, communications systems and safety equipment
	5. royalties, know-how fees, insurance, duties, taxes, financing during construction
	6. startup expenses
	7. contingency for unexpected delays or labor problems
	8. initial charges such as catalysts, solvents, heat transfer media

TABLE 3. COST COMPONENTS (from Campbell et al (1978))

	Cost Component		Factor
1.	Total equipment cost FOB	1.0	
2.	Installation factor	1.6	
3.	Installed cost	1.6 x 1.0	1.6
4.	Tax, freight, and insurance	0.08 x 1.0	0.08
5.	*Total Physical Plant Cost*		1.68
6.	Contractor's fees	12% of (5)	0.20
7.	*Contract Cost*		1.88
8.	Engineering expense	10% of (7)	0.19
9.	Field expense	5% of (7)	0.09
10.	Legal and other	2% of (7)	0.04
11.	Contingency	6% of (7)	0.11
11a.	*Fixed Capital Investment*		2.31
12.	Interest during construction	6% of (7)	0.11
13.	Working capital	1.5% of (7)	0.03
14.	*Bonded Capital Cost*		2.45

mid 1970 when the Marshall and Swift Inflation Index was 300*. The implications of this will be discussed in the section "Accounting for Inflation". The procedure for estimating the pertinent capital cost is summarized in Figure 2. Some example costs for some sludge disposal units are given in Figures 3 to 11. All these are correlated in terms of the influent capacity to the complete plant. All data are given as the contract cost in 1970 for an MS = 300.

In Figure 3, the data from the two sources are in very poor agreement. The different curves in van Note et al's data arise because the upper curve refers to sludge with an alum or ferric chloride addition. For rotary vacuum filters, shown in Figure 6, the cost depends dramatically upon the quality of sludge being filtered. Culp et al merely distinguish between fresh and digested sludge (with the fresh being about 0.85 that of the digested). Van Note et al record nine alternative qualities of sludge depending upon whether the sludge is fresh or digested, whether it is heat treated and the combination of primary, secondary, secondary with alum addition, and one or two stage lime addition. From their data the digested primary, secondary sludge including alum addition agrees reasonably well with Culp et al's "digested" sludge. However, the heat treated dewatering is about 50% of this value while the fresh primary with two stage lime treatment is 80% higher. In Figure 10, again the difference in the quality of the sludge causes a large difference in capital cost. The contract cost for multiple hearth incinerators again shows a great sensitivity to the quality of sludge. All the sludge incinerated was dewatered via a rotary vacuum filter. Agreement is reasonable between Culp's data and that of van Note et al (1976). The cost of a dissolved air flotation unit correlated in terms of the flow to the D.A.F. unit itself is given in Figure 12. McMichael's data, given in Figure 5, were originally correlated in terms of the total volumetric flow to the front of the plant. The actual flow to the dissolved air unit we assume was 1/100-th of the total inlet flow. This is based on a consistency check with McMichael's other data correlated in terms of

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* Two bases were chosen for this paper to make it consistent with two other reports: Campbell et al (1978) and Woods et al (1975a) (1975b) (1974) (1976) (1977) (1978).

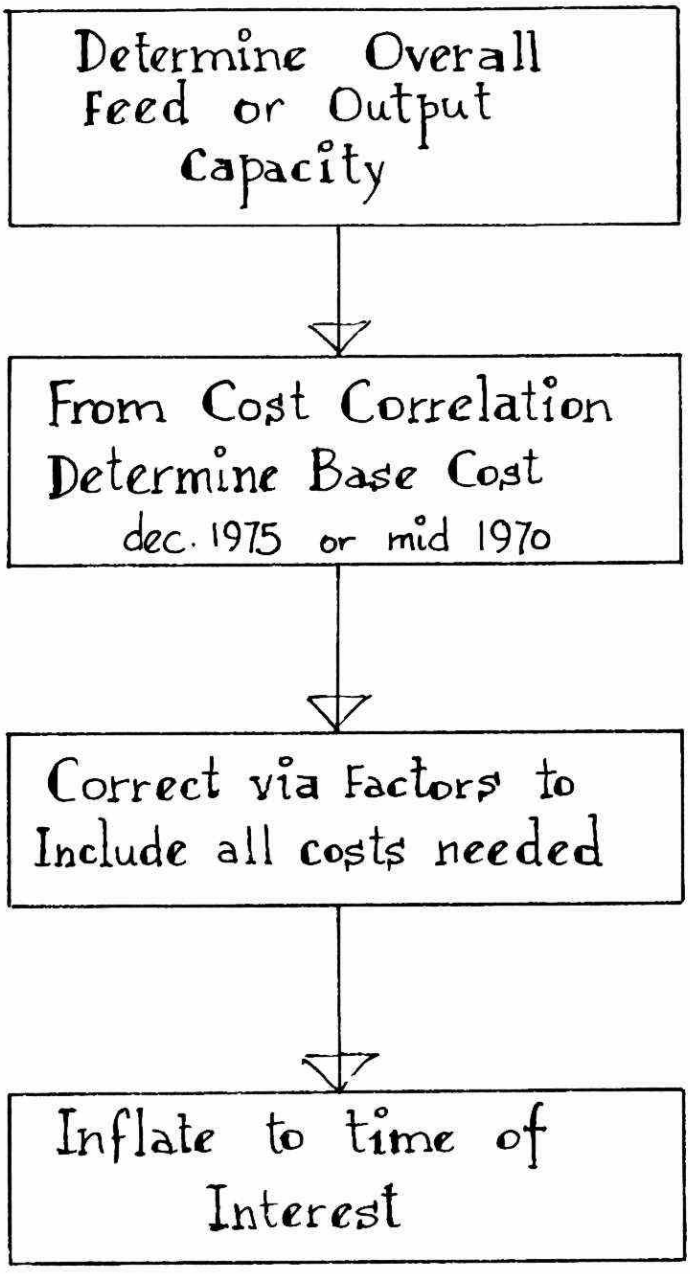

Determine Overall Feed or Output Capacity
From Cost Correlation Determine Base Cost
dec. 1975 or mid 1970
Correct via Factors to Include all costs needed
Inflate to time of Interest

Fig 2: Strategy for Using Cost Correlations

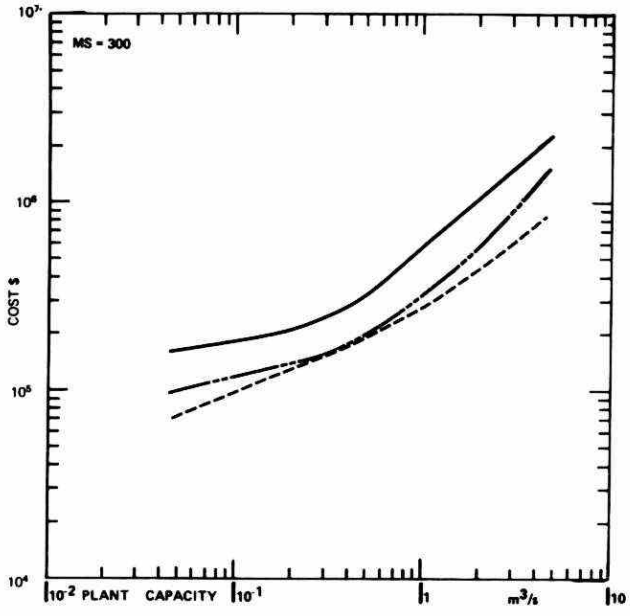


FIGURE 3. ANAEROBIC DIGESTION INCLUDING PRIMARY DIGESTER, MIXER, HEATER, SECONDARY DIGESTER AND SLUDGE PUMP. CONTRACT COST EXCLUDING CONTINGENCY, LAND, LEGAL, ENGINEERING, FINANCING AND ADMINISTRATION.

feed: sludge from conventional primary and from one of conventional trickling filter, conventional of high rate activated sludge (Van Note et al, 1975). ----------

feed: as above but with alum or Fe Cl_3 addition to either primary or secondary (Culp et al, 1974). ----------

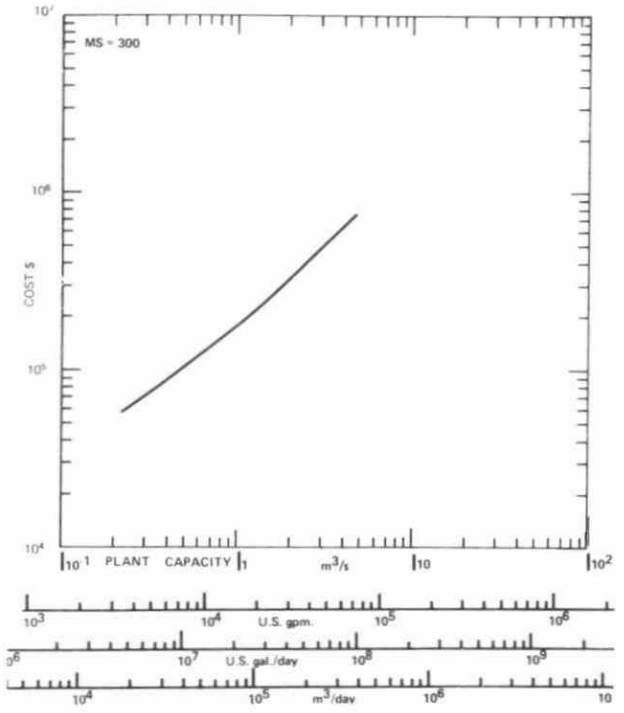


FIGURE 4. SLUDGE THICKENING. CONTRACT EXCLUDING CONTINGENCY, LAND, LEGAL, ENGINEERING, FINANCING AND ADMINISTRATION (CULP et al, 1974).

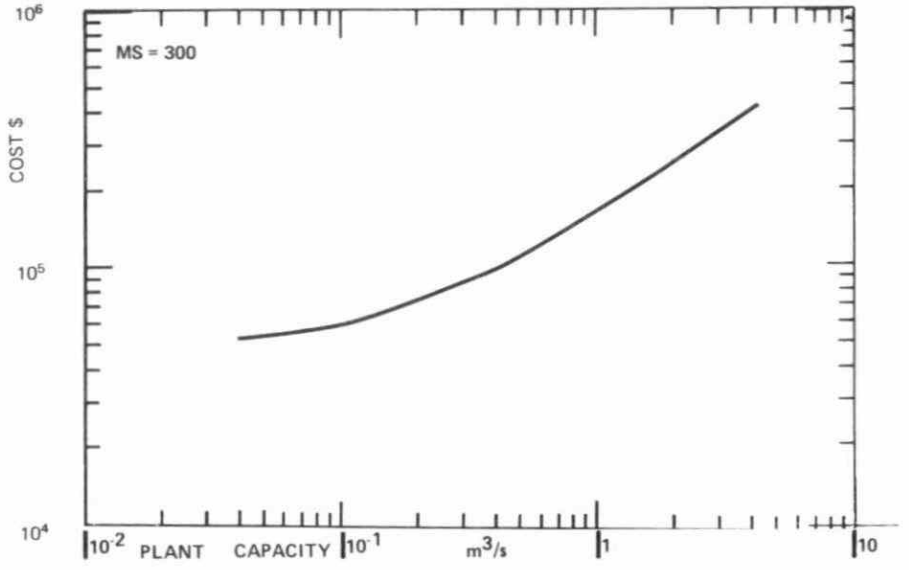


FIGURE 5. DISSOLVED AIR FLOTATION INCLUDING POLYMER ADDITION. CONTRACT COST EXCLUDING CONTINGENCY, LAND, LEGAL, ENGINEERING, FINANCING AND ADMINISTRATION (McMichael, 1974).

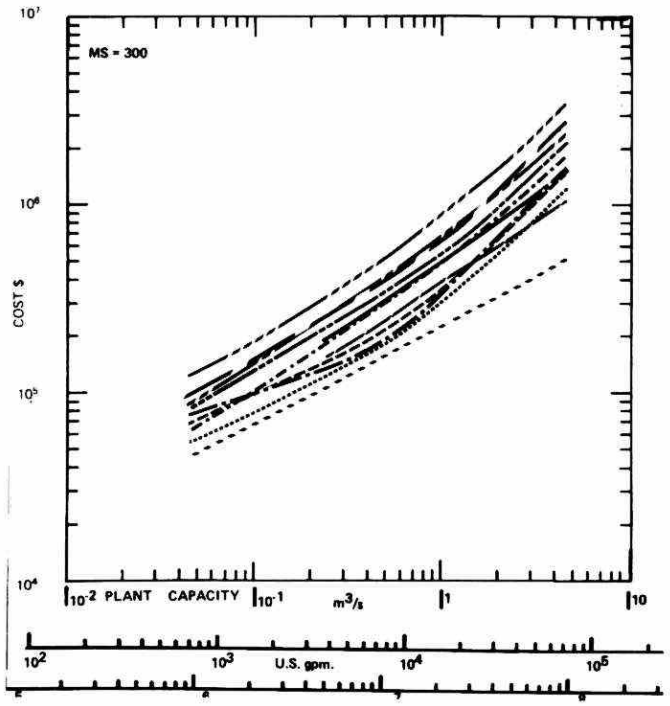


FIGURE 6. SLUDGE VACUUM FILTRATION INCLUDING FILTER FILTRATE RECEIVER, FILTRATE PUMP AND VACUUM PUMP. CONTRACT COST EXCLUDING CONTINGENCY, ENGINEERING, LAND, LEGAL, FINANCING AND ADMINISTRATION.

Culp et al, 1974	feed: fresh sludge	
	feed: digested sludge	
Van Note et al, 1975	feed: primary and conventional secondary	
	feed: primary and secondary with alum or Fe Cl_3 addition	
	feed: primary sedimentation with two stage lime addition	
	feed: primary sedimentation with single stage lime addition plus conventional secondary.	
	feed: digested primary and conventional secondary.	
	feed: digested primary and secondary with alum or Fe Cl_3 addition.	
	feed: two-stage tertiary lime treatment	
	feed: heat-treated primary plus secondary conventional.	
	feed: heat-treated primary plus secondary with alum or Fe Cl_3 addition.	

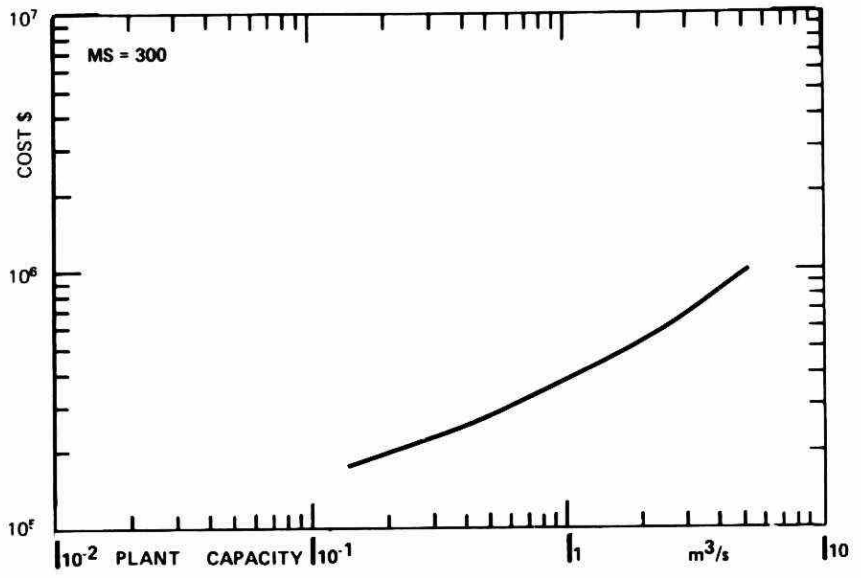


FIGURE 7. ORGANIC SLUDGE CENTRIFUGATION BASED ON THE REQUIRED CAPACITY BEING AVAILABLE WITH ONE CENTRIFUGE OUT OF SERVICE; BASED ON 5% SOLIDS FEED. CONTINUOUS OPERATION. CONTRACT COST EXCLUDING CONTINGENCY, LAND, LEGAL, ENGINEERING, FINANCING AND ADMINISTRATION (Culp et al, 1974).

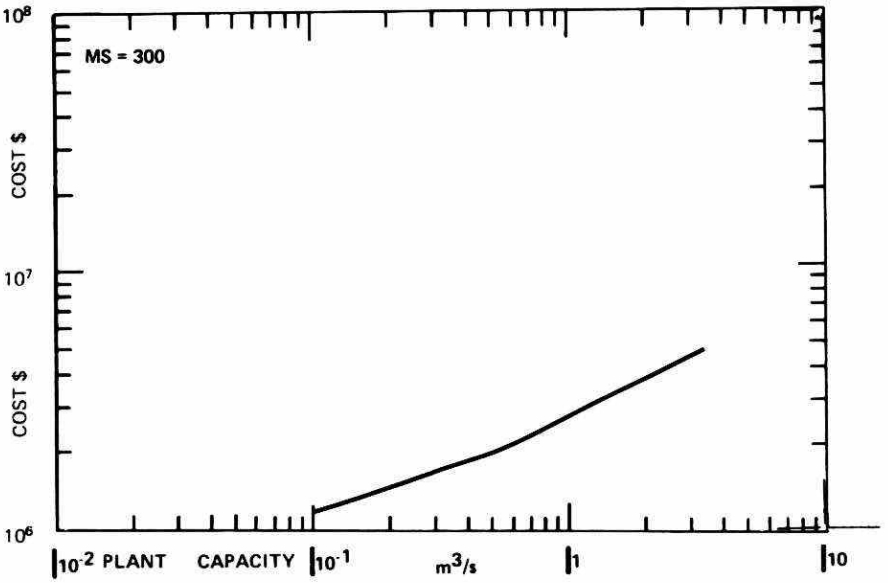


FIGURE 8. LIME SLUDGE THICKENING, DEWATERING AND RECALCINING. CONTINUOUS OPERATION. CONTRACT COST EXCLUDING CONTINGENCY, LAND, LEGAL, ENGINEERING, FINANCING AND ADMINISTRATION (Culp et al, 1974).

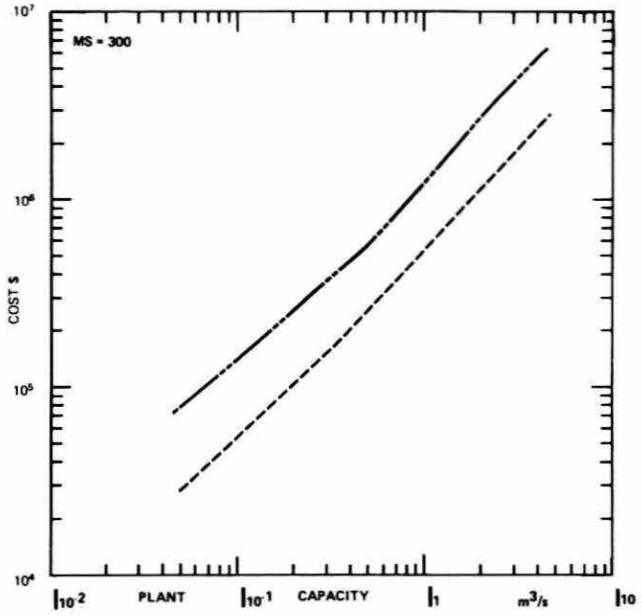


FIGURE 9. AIR DRYING INCLUDING BED, UNDERDRAIN AND SUMP. CONTRACT COST EXCLUDING CONTINGENCY, LAND, LEGAL, ENGINEERING, FINANCING AND ADMINISTRATION.

Van Note et al, 1975 feed: digested primary plus secondary-conventional

feed: digested primary plus secondary with alum or Fe Cl_3 addition.

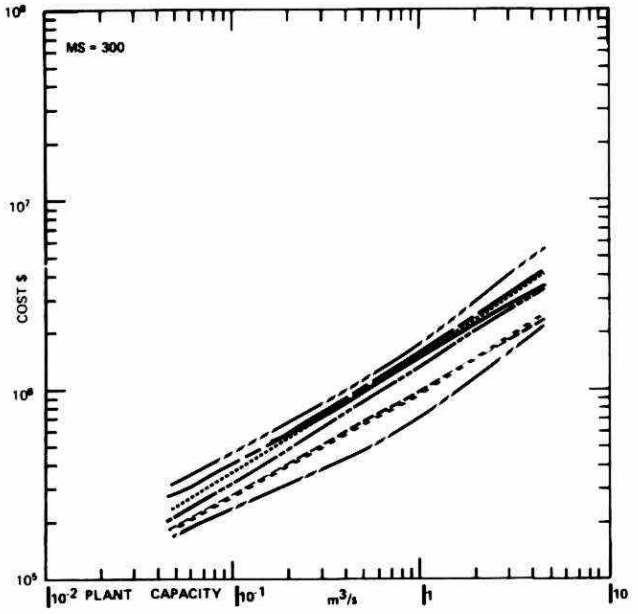


FIGURE 10. SLUDGE INCINERATION VIA MULTIPLE-HEARTH INCLUDING CONVEYOR, BURNER, AFTERBURNER AND AIR SCRUBBERS. CONTRACT COST EXCLUDING CONTINGENCY, ENGINEERING, LAND, LEGAL, FINANCING AND ADMINISTRATION (Culp et al, 1974).

Van Note et al, 1975 feed: vacuum filtered primary plus conventional secondary.

feed: vacuum filtered primary plus secondary with alum or Fe Cl_3 addition.

feed: vacuum filtered primary sedimentation plus two stage lime addition.

feed: vacuum filtered primary with single stage lime addition plus conventional secondary

feed: vacuum filtered tertiary two stage lime plus conventional primary and secondary

feed: vacuum filtered heat treated primary plus conventional secondary

feed: vacuum filtered heat-treated primary plus secondary with alum or Fe Cl_3 addition.

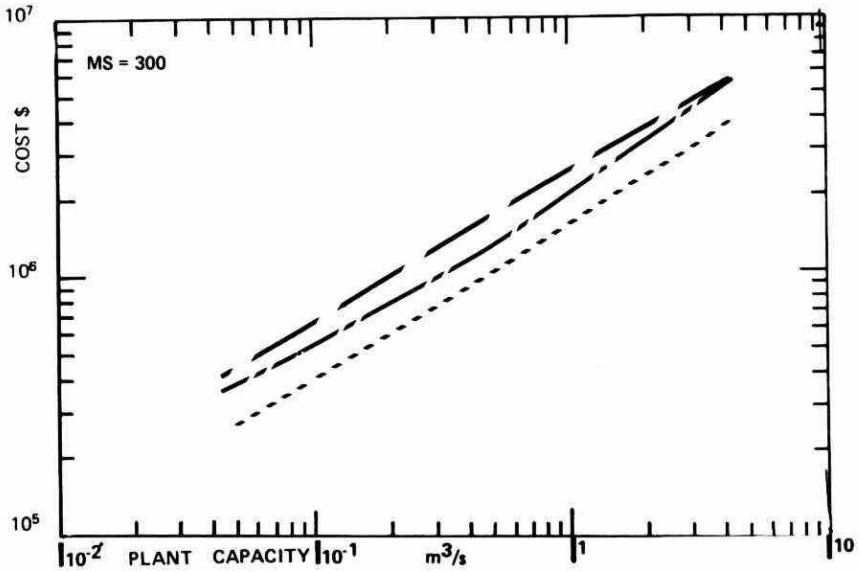


FIGURE 11. RECALCINATION PACKAGE INCLUDING SLUDGE CONVEYOR MULTIPLE HEARTH FURNACE, CO_2 COMPRESSOR, CONVEYOR, STORAGE HOPPER, LIME MAKEUP TANK, SLAKER, SLURRY TANK AND PUMP. CONTRACT COST EXCLUDING CONTINGENCY, ENGINEERING, LAND, LEGAL, FINANCING AND ADMINISTRATION.

Van Note et al, 1975 feed: vacuum filtered two stage lime addition in the primary

feed: vacuum filtered one stage lime in primary plus sludge from the secondary.

feed: vacuum filtered sludge from two stage tertiary lime.

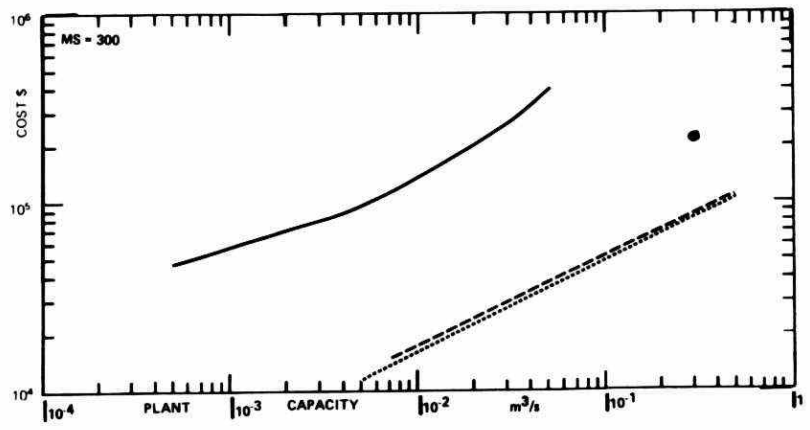


FIGURE 12. DISSOLVED AIR FLOTATION AS APPLIED TO CLARIFICATION AND TO THICKENING. INSTALLED PACKAGE EXCLUDING BUILDING, ENGINEERING, LAND, LEGAL, CONTINGENCY.

For clarification:	Forbes and Witt, 1965	- - - - - - - - - -
	Simonsen, 1962	— — — — — — —
For thickening:	McMichael, 1974	•
	x $^1/1.35$ to yield contract cost	———————

cross-sectional area and an assumed hydraulic design loading of 1400 US gal/ft^2 day. The cost we can infer excludes the building cost. The cost for thickening applications includes the cost of the polymer addition equipment whereas the data for clarification excludes this cost. These Figures 3 to 12 illustrate the type, generality and variability of the data available.

The Module Cost Estimation Method

The cost of complete packages based on average conditions is usually inadequate. What we want is a more accurate method to cost the unique process configuration that we as engineers design to solve specific process problems. Hence we want to be able to size the process equipment that we need and convert that size into the cost of a ready-to-work process unit.

The procedure, summarized in Figure 13, centers around the FOB cost of the major pieces of equipment needed in the process. From this, by the use of appropriately chosen factors, all the rest of the costs can be built up. Some precautions are needed because of the wide variety of terminology and procedures suggested in the literature and as used by different contractors and suppliers.

Here are some definitions:

- FOB cost of the prefabricated process equipment is the cost at the supplier excluding freight, taxes and duties. In the present context this is assigned a value of 1.00.
- Delivered or purchased cost of prefabricated process equipment is the cost at the construction site. It is the FOB cost plus freight, taxes and duties. Often this is between 10 and 14% above the FOB price although we have consistently used 8% in this paper. Thus, delivered cost = 1.08 FOB cost.
- Installed cost. This term needs to be defined in the context. Historically the installed cost for process equipment has meant the cost of inspecting, uncrating and hauling to the installation site and the cost of the materials and labor to hook up the process equipment into an already existing environment. That is, the cost excludes the cost of the

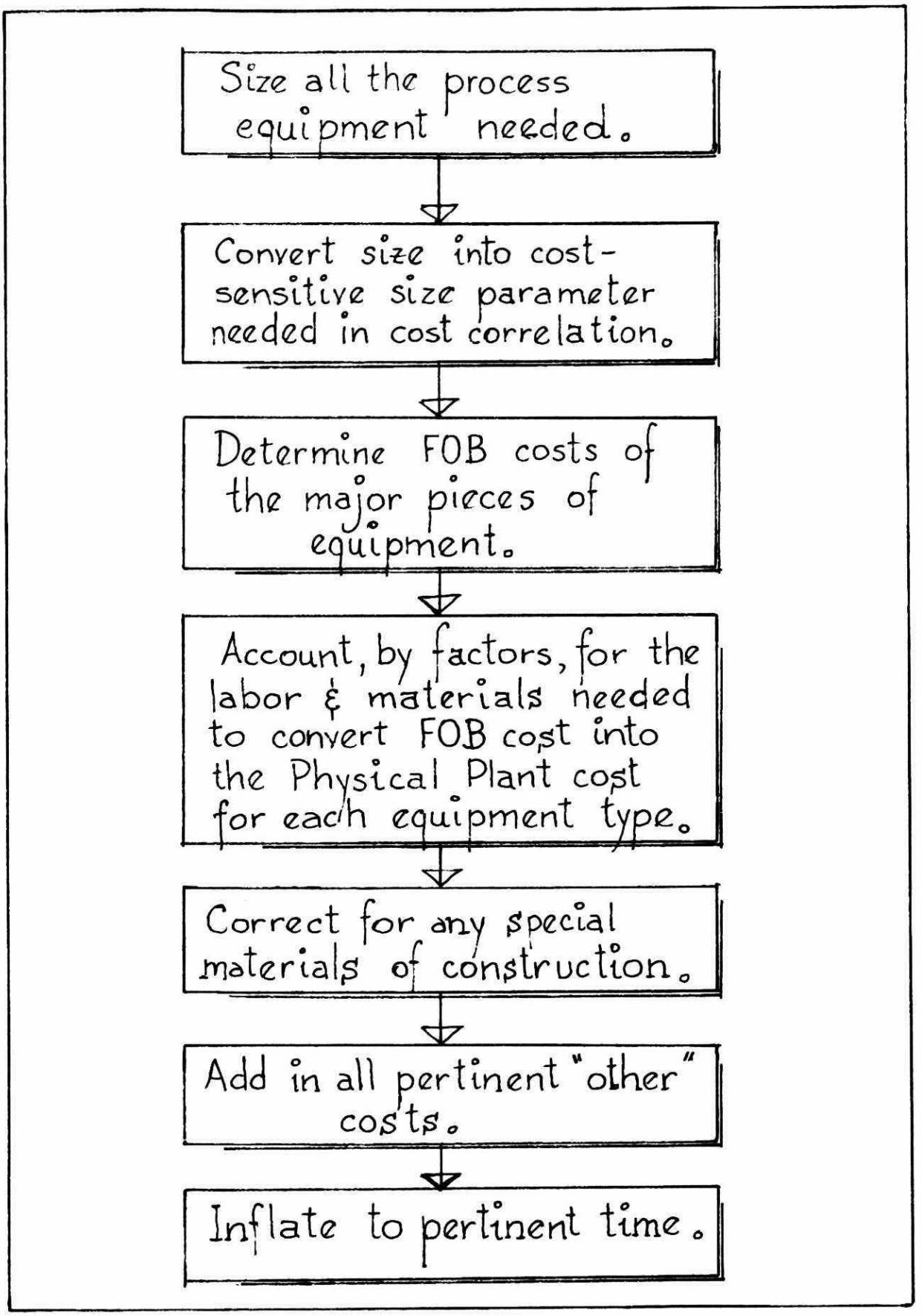

Size all the process equipment needed.
Convert size into cost-sensitive size parameter needed in cost correlation.
Determine FOB costs of the major pieces of equipment.
Account, by factors, for the labor & materials needed to convert FOB cost into the Physical Plant cost for each equipment type.
Correct for any special materials of construction.
Add in all pertinent "other" costs.
Inflate to pertinent time.

FIGURE 13. STRATEGY FOR USING FACTOR METHODS

structural steel, piping, concrete, and instruments etc. The cost of this type of installation is about 45 to 50% of the delivered cost. Thus, installed cost = 1.45 delivered cost. For concrete work, the installed cost of reinforced concrete ($200 to 250 per cubic yard, July 1976) includes the site and forms preparation, steel, delivering and pouring concrete, labor, routine tools, and dismantling the forms.

- Delivered and field erected. The costs include the FOB costs for sections of the unit, the freight, duties and taxes and the erection on a prepared site of the complete entity. This may or may not include hook up, and often excludes the concrete pad or basin.

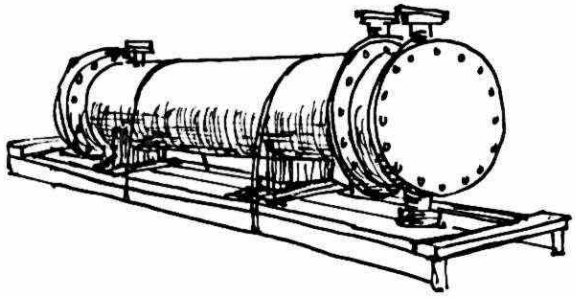
All these above costs (with the exception of the concrete) exclude the costs of creating the environment to which the equipment will be hooked up. The complete set of costs needed to convert an FOB cost into a working unit are summarized in Table 4.

In this example, a $1000 item of process equipment cost about $4000 as a completely working unit. There are several features to note in this example. First, the initial starting number was the FOB supplier price. Next, cost contributions 3 to 12 are what we can visualize as the total material and labor cost to build up a working package on top of a level section of ground. In Figure 14 we illustrate this process for a heat exchanger. On the left is the FOB equipment; on the right is the working unit. In this example, the materials and labour cost directly associated with this working unit is $2520. Naturally the size of what we mean by a working unit will dramatically affect the cost. We select the boundary of the working unit module being within about 3 m of the outer boundary of the process equipment. The distance is chosen so that ideally we can slide modules of different types of equipment together and neither have a double counting of the cost nor miss out any cost contributions. That is, we can add the pump module to a primary clarifier module and get an estimate of the combined bonded cost that is accurate to within $\pm$ 30%. Thus in the so-called bare module factor method used here the cost factors will account for all material and labor expenses incurred within a module boundary surrounding each type of equipment. Different factors will be used for different types of equipment.

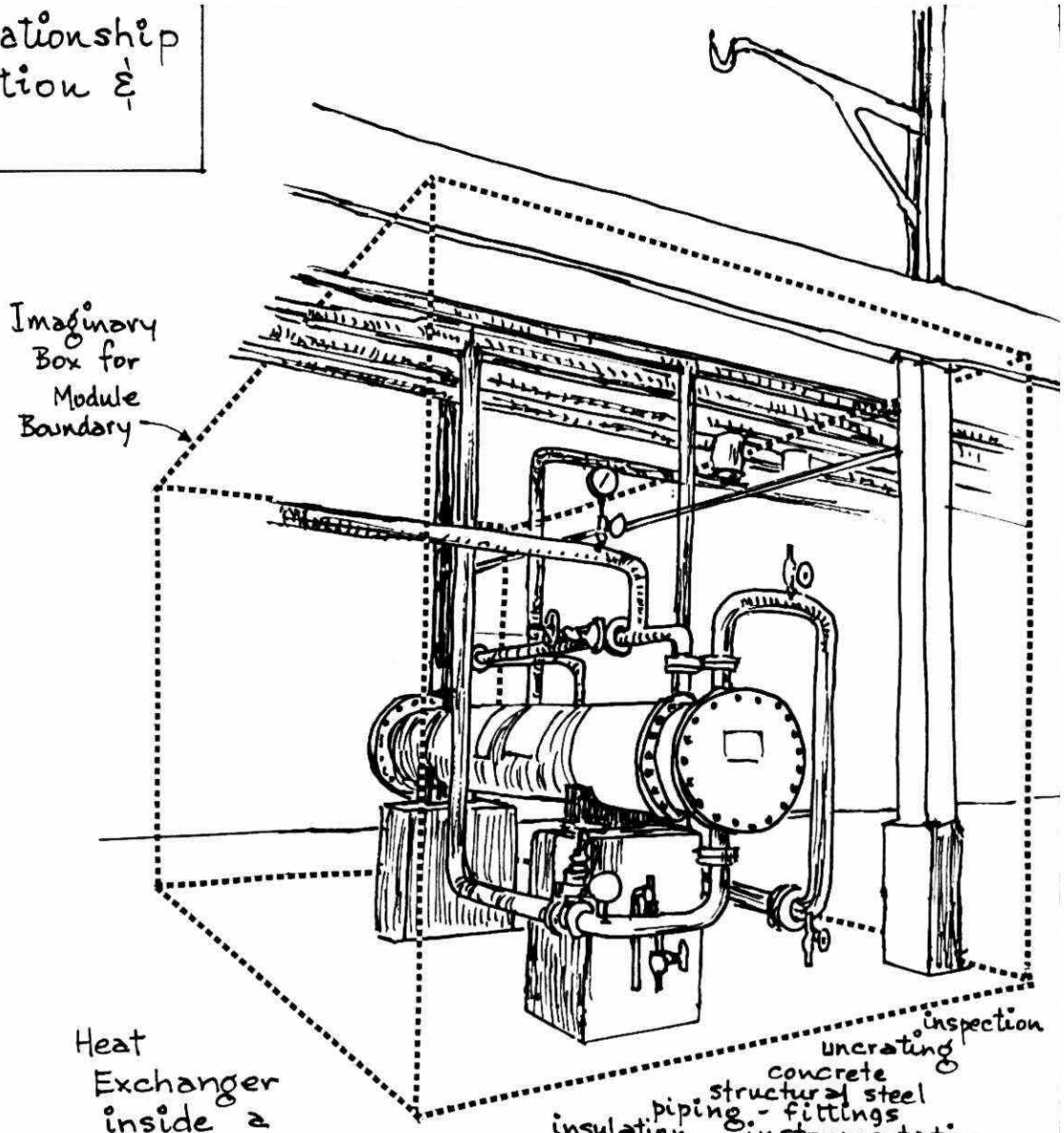
TABLE 4. CAPITAL COST COMPONENTS

Item	Materials		Labour	Total	Name
1. F.O.B. equipment	$1000			$1000	F.O.B.
2. Freight, tax duties		(80)		80	
				1080	Delivered
3. Uncrate, inspect Transport and hook up			450	450	
				1530	Installed
4. Piping	300	+	125	425	
5. Instruments	30	+	10	40	
6. Insulation	30	+	10	40	
7. Paint	10	+	15	25	
8. Electrical	310	+	60	370	
9. Concrete	50	+	20	70	
10. Structural Steel	10	+	10	20	
11. Buildings			-		
12. Offsites					
M $:	1740	L:$	700	2520	Physical Plant
13. Contractor fees		(300)		300	
13a. Freight,tax, duties				2820	Contract
14. Engineering expense		(280)		280	
15. Field expense		(140)		140	
16. Legal and other		(55)		55	
17. Contingency		(170)		170	
				3465	Fixed Capital Investment
18. Interest during construction		(170)		170	
19. Working capital		(40)		40	
				3675	Bonded Cost
20. Startup and tests		(300)		300	
				3975	Turnkey

FIGURE 14: An illustration of the relationship between an FOB supplier situation & the Module unit.



Heat Exchanger FOB supplier



Heat Exchanger inside a Module

Woods 76

Returning to Table 4 we note that there are several alternative ways that we can account for the cost components:

1. Separate material and labor breakdown for each cost item, e.g. piping: $300 material and $125 labor.
2. A total cost contribution for each cost item, e.g. piping $425.
3. Separate material breakdown for each cost item and a total labor for the module, e.g. piping $300 materials and total module labor of $700.

Within any contracting company one preferred method will be used. In the literature, Bauman (1964) uses method 1, Chilton (1949) uses method 2, and Guthrie (1969) (1974) uses method 3. In this paper we use method 3. Note that the freight, tax and duties are neither materials nor labor and are usually added in after contractor's fees. We need to introduce some new terms:

L & M - the field labor and material expenses (including the initial FOB cost) associated with creating a working unit. This excludes building and off sites, contractor's fees, and freight, taxes and duties. In the example this is $700 + 1740 = $2440.

(L/M) - the ratio of the field labor to total material cost within the module. In the example this is $700/1740 = 0.40.

(BM) - the costs attributed to all expenses incurred in creating a working unit and all necessary ancillary piping, instruments and supports within an envelope surrounding the equipment and about 3 m away from the equipment. This cost includes freight, duties and taxes, engineering expense, field expense but excludes contractor's fees, legal, contingency, interest, working capital and start-up.

This particular definition is used extensively in the process industry. However, this is awkward to use in the environmental context because the contractor's fees are excluded in the BM while the engineering fees are

included in the BM. Hence, this term will not be used in this paper. Nevertheless, because of its use elsewhere (see Guthrie, 1974; 1969) we have included it here for information. In the example the BM cost would be $2520 + 280 + 140 = $2940.

The Total Module (TM) - the total module factor concept has been developed outside the environmental area and represents the bare module cost plus the contractor's fees, and contingencies. In this example the value is $3465 less legal of $55 or $3410.

The Contract Module (CM) - a concept important to the environmental area is the L & M cost plus the contractor's fees and freight, tax and duties. In this example the value is $2820.

The whole idea behind this factor method is that the labor plus material costs are reasonably constant percentages of the FOB cost for any particular type of process equipment. However, the percentages differ for different equipment types. By carving a process up into the appropriate modules, the L & M cost can be estimated reasonably accurately by accounting for the specific L & M factors for each module type.

To use this method requires that we have reasonable estimates of the FOB costs of various process equipment and reliable L & M factors.

Estimates of the L & M Factors

The value of the L & M factors depends upon the materials of construction of the equipment in the module, the size of the expenditure or total project and the unique characteristics of the specific module relative to average modules. Furthermore, within any company the L & M factors will be consistent because a consistent method of identifying a module and allocating expenses to that module can be developed. However, L & M factors for one company may be completely different from another. Consider each of these characteristics in turn.

Table 5 shows the effect of project size on the L & M factors for a carbon steel pump and drive. For small pumps, in isolated locations the module factors are very large, with the materials factor

TABLE 5. MATERIAL FACTORS FOR PUMPING UNITS BASED ON F.O.B. PUMP PLUS MOTOR DRIVE FOR CARBON STEEL CONSTRUCTION

Thousand of 1970 $	Isolated Installation $1	$2	$5	$10	$20	Integrated
Pump F.O.B.	1.00	1.00	1.00	1.00	1.00	-
Piping	1.7	0.90	0.40	0.23	0.15	0.293
Concrete	0.08	0.065	0.055	0.048	0.040	0.039
Steel	-	-	-	-	-	-
Instruments	1.80	1.00	0.45	0.26	0.16	0.029
Electrical	0.70	0.60	0.55	0.38	0.30	0.303
Insulation	0.18	0.12	0.07	0.052	0.04	0.028
Paint	0.0033	0.0018	0.0007	0.00035	0.0002	0.008
Materials M:	5.46	3.69	2.53	1.97	1.69	1.70
Labor L:						0.679
L&M:						2.379

TABLE 6. INSTALLATION FACTORS[1] FOR DEWATERING EQUIPMENT (L& M)

Unit Process	Factor	Comments
Gravity Thickening	1.6	
Dissolved Air Flotation	1.5	
Solid Bowl Scroll Centrifuge	1.6	based on 316 s/s
Basket Centrifuge	1.57	based on 316 s/s
Vacuum Filter	1.6 - 2.0	
Plate & Frame Pressure Filter	1.79	

[1] Does not include buildings

about 5.5. For large size pumps or pumps integrated into a process network with many pumps then the material module factors are around 1.70.

If the materials of construction are not carbon steel then complications can arise. From Table 5, a $10,000 (1970) pump might have an electrical materials expense of $3,800 so that the electrical materials factor is 0.38. The same size pump in stainless steel might cost $15,000 but it will have the same electrical materials expense of $3,800. Hence, for this material of construction the electrical materials factor will be $3,800/$15,000 or 0.25. This complication would mean that we would need a set of L & M factors for each material of construction. To avoid this complication we use one set of L & M factors, namely the ones developed for carbon steel and determine the correct installation L & M data by costing the cost contributions based on carbon steel L & M factors and an "imaginary" carbon steel FOB price for the equipment. For example, if we required a $15,000 (1970) stainless steel pump we would price a carbon steel unit of the same capacity, say $10,000 (1970); apply the factors from Table 5 to determine the actual dollar value of all materials and labor and then add the alloy increment for the FOB unit. In this example the result would be:

FOB actual stainless steel	$15,000	
FOB hypothetical carbon steel	$10,000	
	5,000	alloy increment
L & M factors for integrated installation = 2.379		
Total module cost for carbon steel: 2.379 x $10,000 =	23,790	
Total: alloy increment + module	$28,790	

Other adjustments can be made if the pumping is alloy as well; these adjustments are made to the piping materials component.

The third complication is if special features, contained in the usual modules, are not needed for the specific module of interest. For example, our module may not need any concrete work done. Then, if we have a breakdown of the components in the L & M factors, we can modify the total module factors accordingly.

For the equipment used for sludge dewatering the L & M factors have not been developed in detail. Our best estimates, however, of the total L & M factors are given in Table 6. To simplify the analysis, we have developed the L & M factors for centrifuges in terms of the 316 stainless steel construction since carbon steel units are rarely manufactured.

Estimates of the FOB Cost of Equipment

The FOB cost of equipment can be obtained

a. from equipment suppliers or fabricators,
b. from past experience or from past installations done within your own company,
c. from data reported in the literature.

Ultimately we will want a quotation from a supplier or a fabricator. Such quotations are expensive and time-consuming to prepare, require that we carefully specify what equipment we need and delay decision-making. At the first two stages of selecting process alternatives, we are considering many alternatives, we do not know precisely the equipment details, and we must narrow our choices down to several fairly quickly. Hence, at this stage we cannot and should not contact suppliers. It wastes their time and ours. Fortunately estimates that are within $\pm$ 30% can be obtained from a combination of in-house and open literature information.

To be useful such data need to describe:

1. the date of the cost information,
2. the type of cost: FOB, delivered, installed, delivered and field erected, grass roots, battery limits,
3. the materials of construction,
4. the various capacity and size parameters associated with the equipment,
5. a listing of all the components included in the cost and hopefully some important features that were excluded.

Usually the data are plotted on log-log paper and the correlating equation is of the form:

$$\text{Cost}_{\text{size 1}} = \text{Cost}_{\text{size 0}} \left(\frac{\text{Size 1}}{\text{Size 0}} \right)^{n}$$

Figures 15 to 22 give estimates of the FOB costs of sludge pumps, gravity thickeners, dissolved air flotation units, solid bowl and imperforate bowl centrifuges, rotary vacuum, pressure and belt filters. The time basis for these graphs is December 1975. In these graphs, only the current recommended correlation is presented. Some details of the basis for these graphs will be given in a later section. Costs are also given in Figures 23 to 29 for anaerobic digesters and incinerators.

Accounting for Inflation

Over 50 different indices have been developed to record how the prices of various commodities, goods and services have changed with time. For example what cost $1000 in 1926 now costs $5632. The challenge is to select the index that most correctly reflects the inflationary trends pertinent to our particular problem. In the environmental area the prime choices are:

a. Engineering News Record or ENR construction index
b. Environmental Protection Agencies - sewage treatment Plant Index (EPA - STP), The Small City Conventional Treatment Index (SCCT) and the Large City Advanced Treatment Index (LCAT)
c. Chemical Engineering Index (CE)
d. Marshall and Swift (or Stevens) index (MS)
e. Individual equipment components from the CE index
f. The Southam Index

Somes values for these different indices are given in Tables 7, 8 and 9.

All these indices work the same way; namely, to find the value for new conditions, we multiply the dollar value at any given time by the ratio of the "new" to "given" values of the inflation index. For example, to find out what $1000 in 1960 is worth in the fourth quarter of 1976 we would multiply $1000 by the ratio of the inflation index given in Table 7.

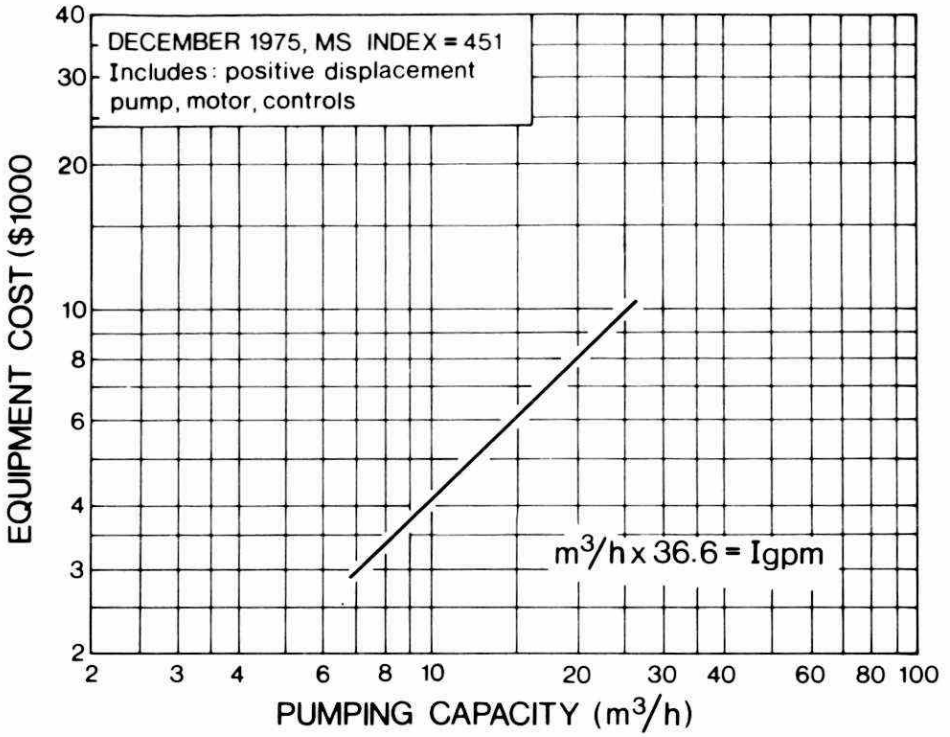


FIGURE 15. EQUIPMENT COST-SLUDGE PUMPS

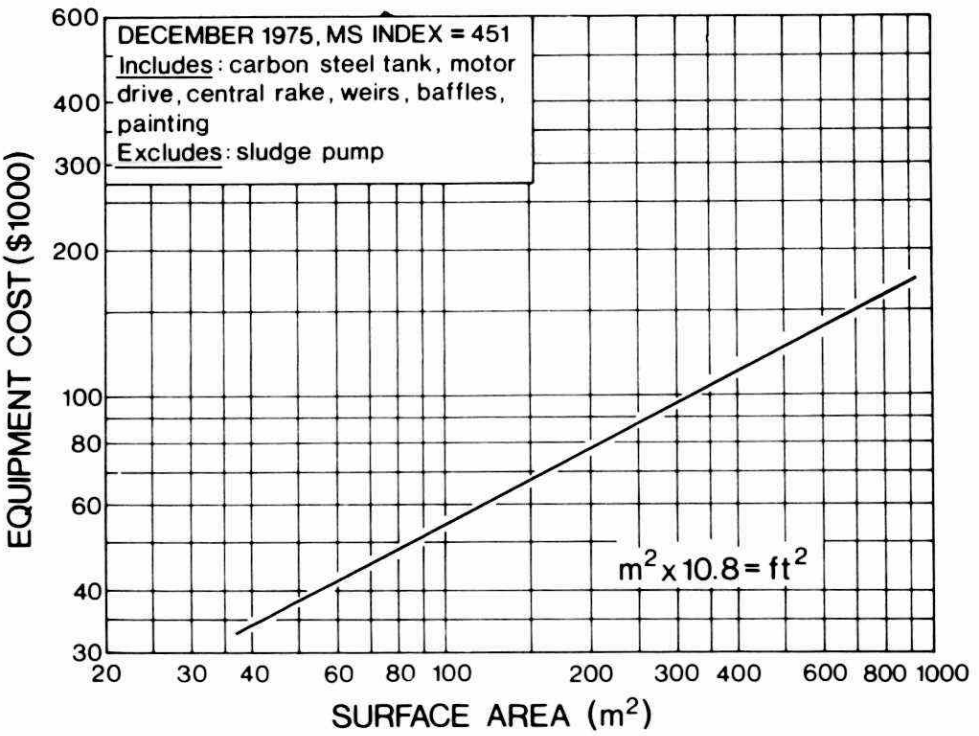


FIGURE 16. EQUIPMENT COST-GRAVITY THICKENERS

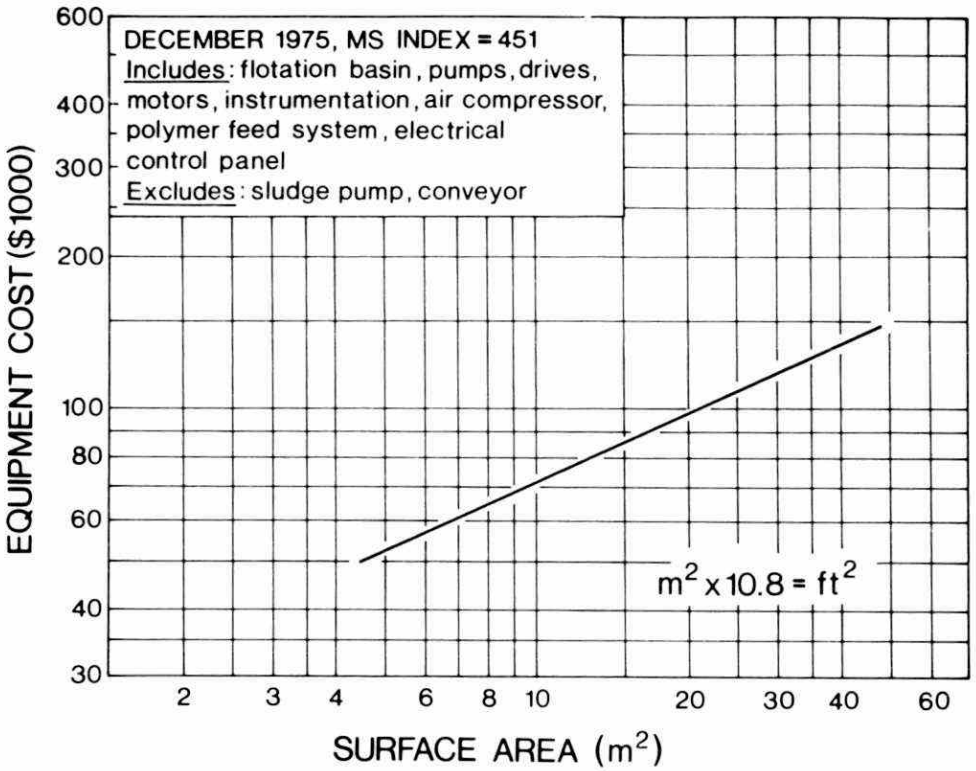


FIGURE 17. EQUIPMENT COST–DISSOLVED AIR FLOTATION

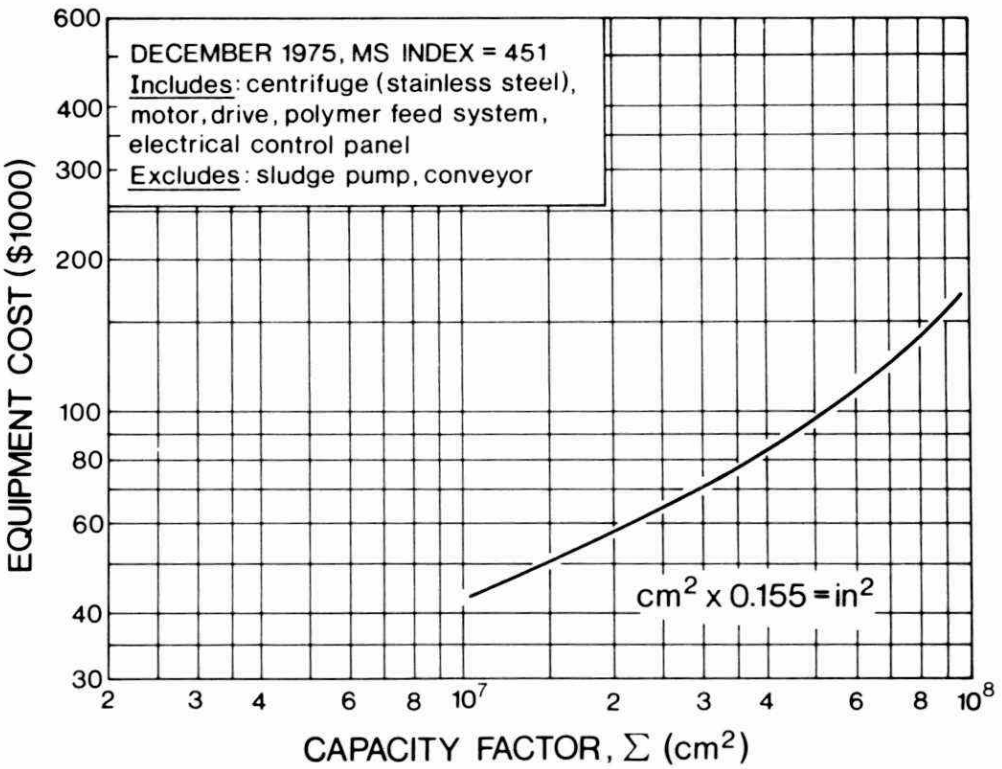


FIGURE 18. EQUIPMENT COST–SOLID BOWL CENTRIFUGE

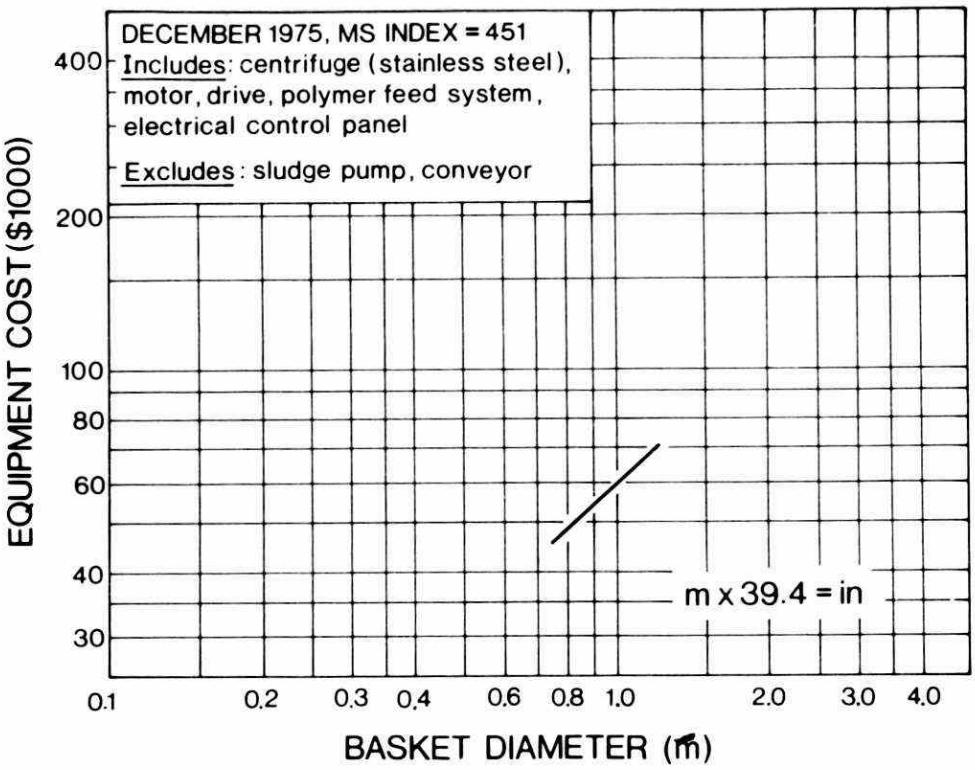


FIGURE 19. EQUIPMENT COST – BASKET CENTRIFUGE

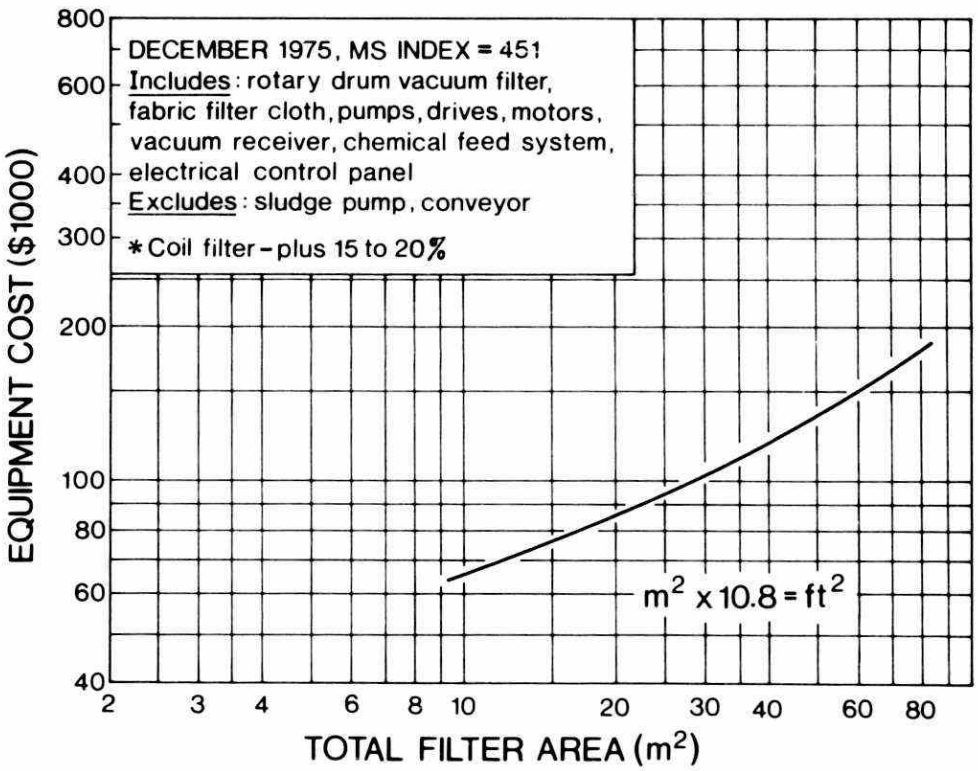


FIGURE 20. EQUIPMENT COST – VACUUM FILTER

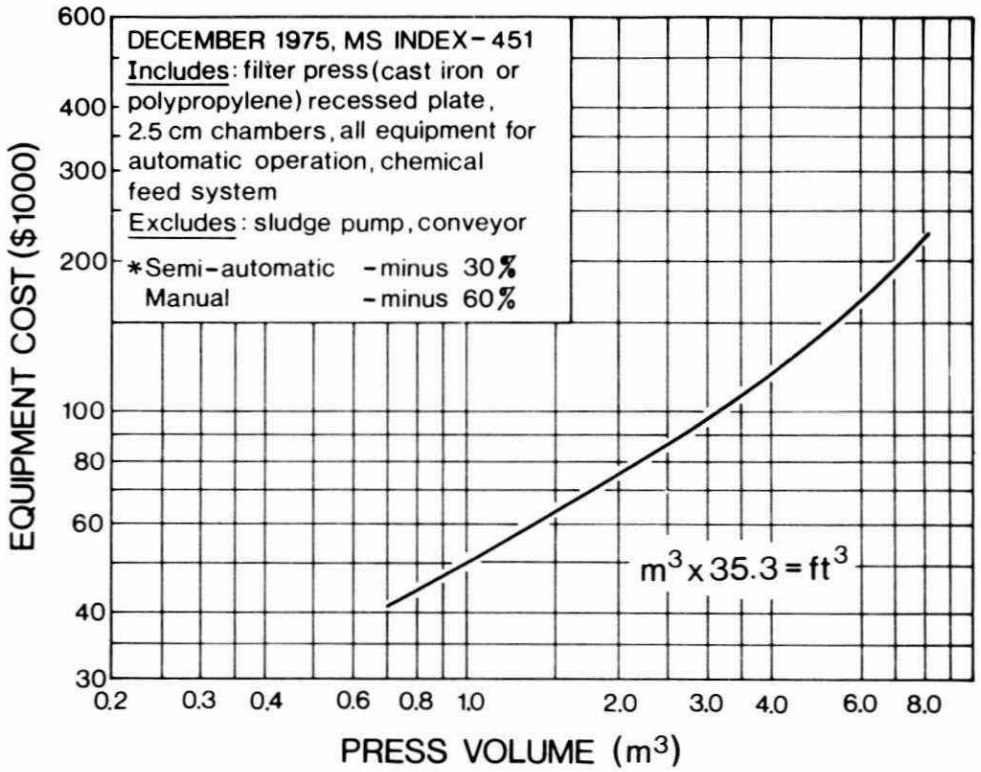


FIGURE 21. EQUIPMENT COST-PRESSURE FILTER

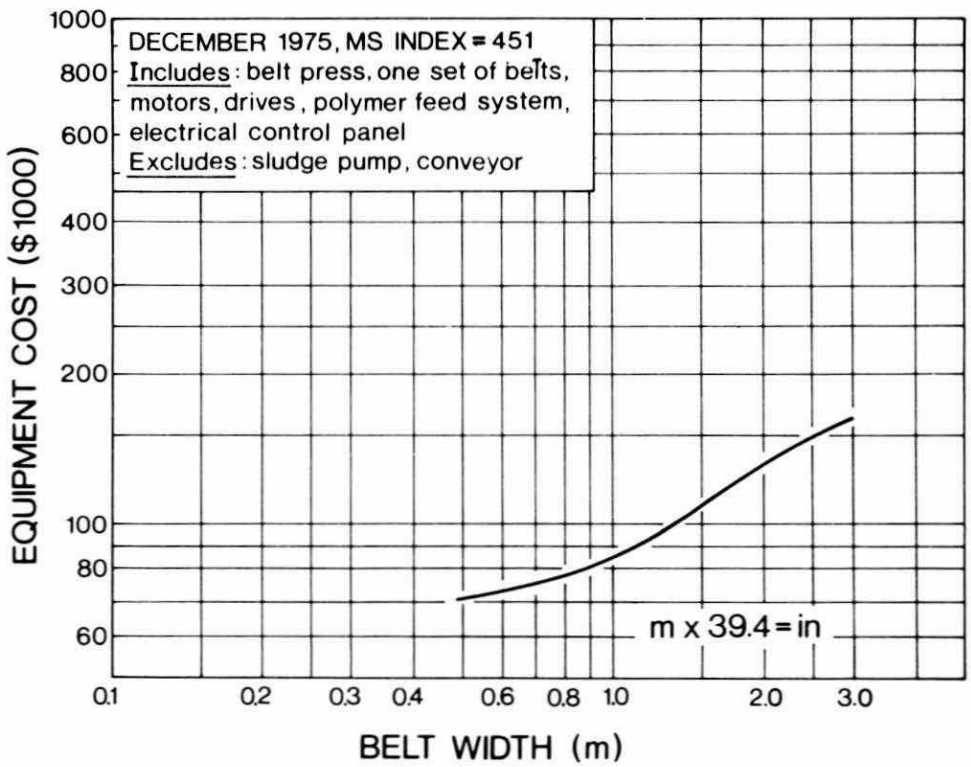


FIGURE 22. EQUIPMENT COST-BELT PRESS

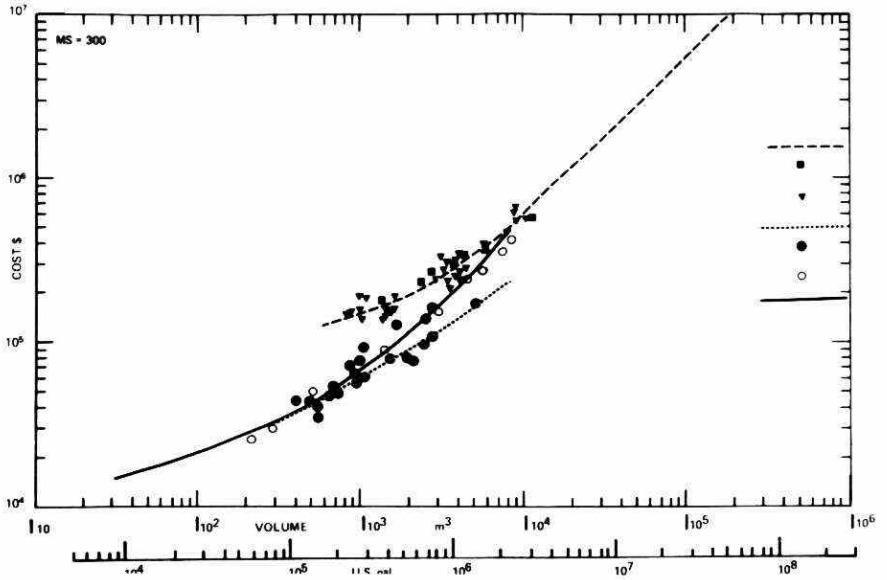


FIGURE 23. ANAEROBIC SLUDGE DIGESTER. INSTALLED INCLUDING ALL HEATING OF SLUDGE, MIXING, GAS REQUIREMENTS, SLUDGE PUMPS, CONCRETE TANKS, DIGESTER COVER, CONTROL BUILDING, INTEGRAL EXCLUDING PIPING AND FROM OTHER PROCESS UNITS, ENGINEERING, OVERHEADS.

Patterson and Banker, 1971 — actual installations; estimates

DiGregorio et al, 1968

Russell and Axon as cited by Smith, 1968

Barnard and Eckenfelder, 1971 — high rate digesters

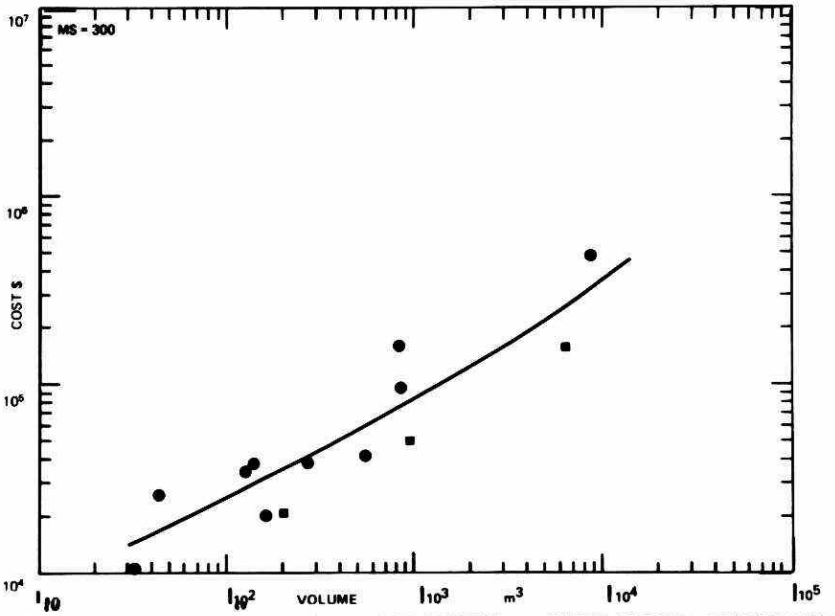


FIGURE 24. SLUDGE HOLDING TANKS; CONCRETE. INSTALLED CONTRACT COST EXCLUDING ENGINEERING, LAND, LEGAL, FIELD EXPENSE, CONTINGENCY AND FINANCING.

Patterson Banker, 1971 — actual installations; estimates

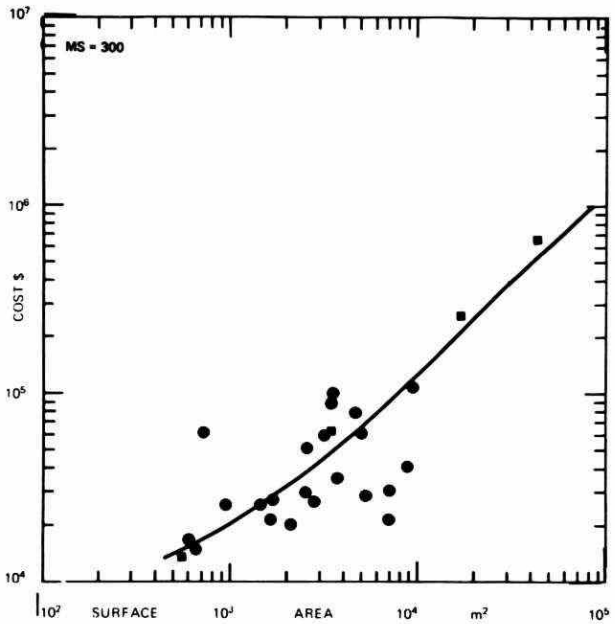


FIGURE 25. SLUDGE DRYING ON OPEN SAND BEDS FOR WASTEWATER TREATMENT PROCESSES. INSTALLED COST INCLUDING NORMAL EXCAVATION, PIPING FOR SLUDGE DISTRIBUTION, SAND AND GRAVEL DRAINAGE BEDS, UNDERGROUND COLLECTION PIPING.

Patterson and Banker, 1971 actual installations ● ——————
estimations ■

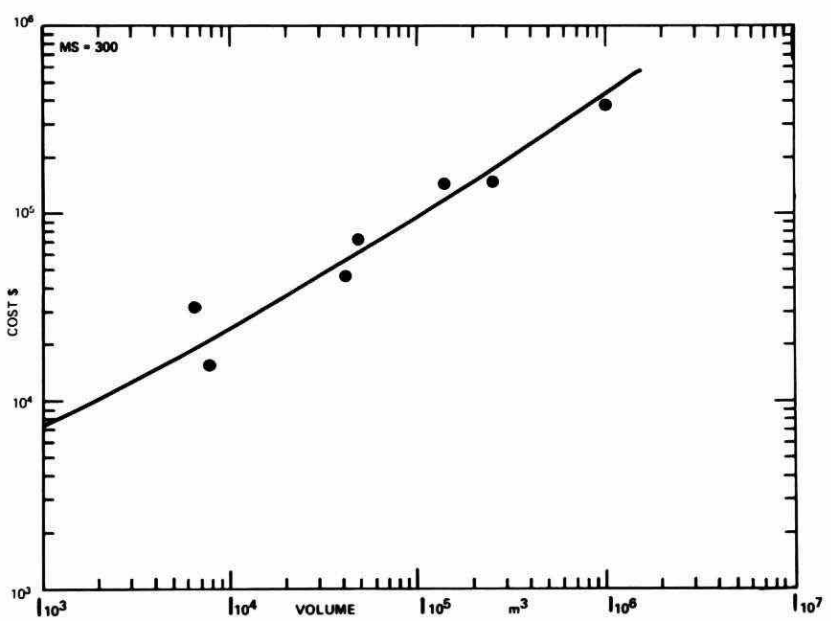


FIGURE 25b. SLUDGE LAGOONS FOR STORAGE AND DRYING OF WASTEWATER SLUDGE AFTER DIGESTION. DEPTH 0.7 TO 3 m WITH ACCUMULATION OF THREE MONTHS TO FIVE YEARS.

Installed with normal excavation, dike construction and sludge distribution piping

Patterson and Banker, 1971 ● ——————

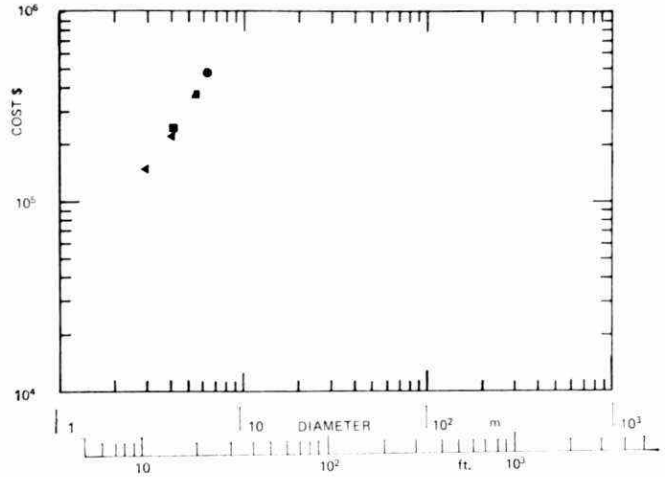


FIGURE 26. FURNACE, MULTIPLE HEARTH, INSTALLED.

Sebastian and Carindal, 1968
5 - hearth ◀
6 - hearth ■
8 - hearth ●

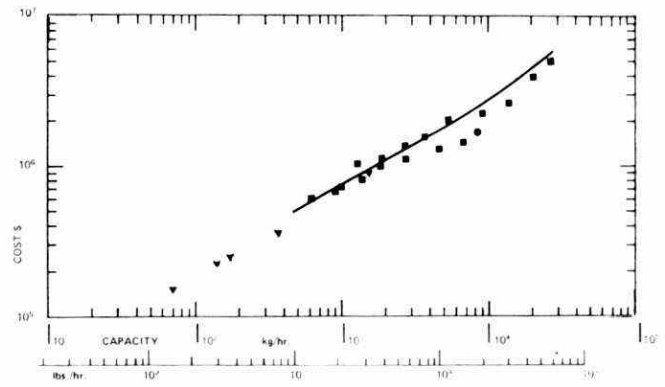


FIGURE 27. FURNACE, MULTIPLE HEARTH, INSTALLED INCLUDING ENCLOSURE, GAS SCRUBBERS AND EXHAUST, ASH HANDLING, FUEL SYSTEM, INSTRUMENTATION, PIPING AND ELECTRICAL.

Patterson and Banker, 1971 for sludge waste treatment plant ■ ——————

Guccione, 1966 ●

Sebastian and Carindal, 1968 ▼

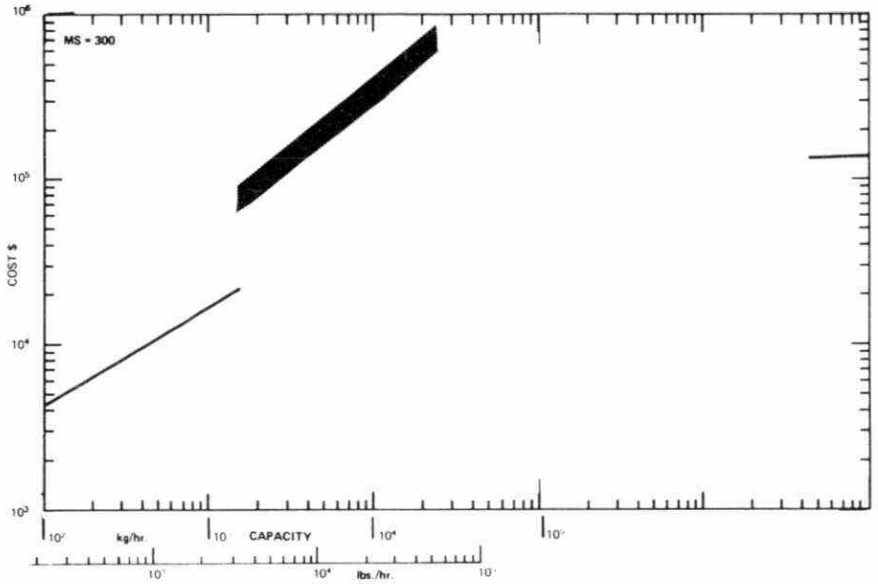


FIGURE 28. ROTARY DRYERS, KILNS OR INCINERATORS. INSTALLED FOR SOLID WASTE DISPOSAL (at 10.5 MJ/kg)

Kerridge, 1973

Page, 1963 delivered and not installed

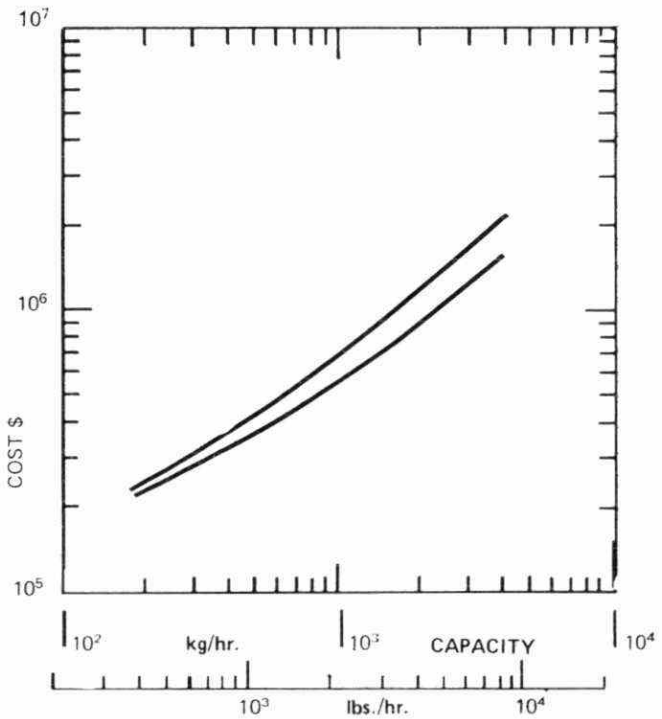


FIGURE 29. FURNACE, FLUIDIZED-BED FOR SLUDGE INCINERATION, INSTALLED INCLUDING SOLIDS PREPARATION (Comminution plus dewatering), CONVEYING, FEEDING, BURNING AND AIR SUPPLY, GAS TREATMENT (Ash removal, gas scrubbing, ash handling), ALL ELECTRICAL PIPING, PLUMBING, ENGINEERING AND CONTRACTOR OVERHEADS

DiGregorio, 1968

TABLE 7. AVERAGE ANNUAL VALUES FOR COST INDICES (from Campbell et al, 1978)

Year	Engineering News Record Construction Cost Index 1913 = 100			Environmental Protection Agency			Marshall and Stevens Installed Equipment Index 1926 = 100
	U.S. National Average	Toronto	Montreal	STP 1957-59 = 100	SCCT 1973 3rd Quar. = 100	LCAT 1973 3rd Quar. = 100	
1960	824	690	660	105	-	-	238
1961	847	701	678	106	-	-	237
1962	872	724	707	107	-	-	239
1963	901	743	736	109	-	-	239
1964	936	782	756	110	-	-	242
1965	971	844	785	112	-	-	245
1966	1021	887	930	116	-	-	252
1967	1070	922	1027	119	-	-	263
1968	1165	1050	1066	124	-	-	273
1969	1272	1082	1211	133	-	-	285
1970	1418	1183	1350	144	-	-	303
1971	1620	1334	1318	160	-	-	321
1972	1670	1536	1415	172	-	-	332
1973	1896	1763	1608	183	-	-	334
1974	2020	1913	1890	210	-	-	398
1975							
1st Quar.	2163	2007	1952	247	-	-	435
2nd Quar.	2248	2076	2086	246	-	-	442
3rd Quar.	2293	2220	2093	251	109	-	447
4th Quar.	2297	2240	2094	255	110	120	451
1976							
1st Quar.	2327	2269	2141	-	113	123	460
2nd Quar.	2413	2461	2273	-	115	126	469
3rd Quar.	2478	2461	2273	-	117	129	477
4th Quar.	2494	2530	2336	-	119	130	485

TABLE 8. ANNUAL AVERAGE VALUES FOR INFLATION INDICES

Year	Marshall and Stevens installed equipment index, 1926 = 100		Chemical Engineering plant construction cost index, 1957 = 100		Southam	Nelson refinery construction index, 1946 = 100		Engineering New-Record construction index,	Environmental Protection Agency STP 1957-59 = 100
	All industry	Process industry	Total	Plant Equipment		Inflation	True cost	1913 = 100	United States national average
1947	151	149	65	60		117	106	413	56
1948	163	162	70	66		133	108	460	65
1949	161	162	71	67		140	109	477	66
1950	168	167	74	70		146	110	510	69
1951	180	178	80	78		157	109	543	74
1952	181	179	81	78		164	109	569	77
1953	183	181	85	81		174	108	600	81
1954	185	184	86	82		180	105	628	83
1955	191	189	88	85		184	103	660	87
1956	209	206	94	93		195	102	690	92
1957	225	224	99	99		206	103	724	98
1958	229	228	100	100		214	104	759	102
1959	235	232	102	102		222	104	797	104
1960	238	237	102	102		228	103	824	105
1961	237	236	102	100	100	233	102	847	106
1962	239	237	102	101		238	100	872	107
1963	239	238	102	101		244	99	901	109
1964	242	241	103	101		252	100	936	110
1965	245	244	104	102	120	261	101	971	112
1966	252	252	107	105	126	273	103	1021	116
1967	263	260	110	108	134	288	104	1070	119
1968	273	268	114	112	144	304	108	1165	124
1969	285	283	119	116	153	329	106	1272	133
1970	303	301	126	123	162	365	118	1418	144
1971	321	321	132	130	179	406	118	1620	160
1972	332	332	137	135	194	429	122	1670	172
1973	344	344	144	142		468	127	1896	
1st Quar. 1974	362		152					1944	
2nd Quar.	386	398	161	165				1989	
3rd Quar.	414		172					2080	
4th Quar.	431		177					2098	
1st Quar. 1975	437		180					2122	
2nd Quar.	444	444	181	182				2185	
3rd Quar.	446		182					2269	
4th Quar.	451		186					2297	
1st Quar. 1976	458		188					2319	
2nd Quar.	469	472	190	192					
3rd Quar.	477		194						
4th Quar.	485		197						
1st Quar. 1977	492		199						
2nd Quar.			201						
3rd Quar.									
4th Quar.									

TABLE 9 COMPONENTS IN THE CHEMICAL ENGINEERING INDEX

Year		Fabricated Equip.	Process Machinery	Pipes, Valves	Instrum, Controls	Pumps Compressors	Elect.	Supports	Total	Erection Labour	Bldngs L & M	Engng Supv.
1970		123	123	132	132	126	100	118	124	137	127	111
1971		130	127	137	140	133	99	127	130	146	136	111
1972		136	132	143	144	136	99	134	135	152	142	112
1973		143	138	152	147	140	104	141	142	158	151	123
1974		170	160	192	165	176	126	172	172	163	166	134
1975		192	184	217	181	208	142	199	195	169	177	142
1976		201	198	232	193	221	149	210	206	174	187	151
1977	1	209	206	239	200	234	155	220	214	177	194	159
1977	2	212	208	246	201	237	158	222	218	176	197	161
	3											
	4											

According to the ENR index, Toronto, the value is:

$$\$1000 \times \frac{2530}{690} = \$3670$$

According to the EPA index, the value is:

$$\$1000 \times \frac{255}{105} \times \frac{119}{113} = \$2560$$

Note that we had to bring the value to the fourth quarter 1975 via the STP index and then shift to the SCCT index.

According to the MS index, the value is:

$$\$1000 \times \frac{485}{238} = \$2040$$

From this example we can see that the choice of index greatly affects the answer.

To determine which index to use we need to carefully consider the basis used to develop the index and to compare the results from the index with actual data.

A comparison of the basis of each index is given by Woods (1975) and by the American Association of Cost Engineers (1969).

For process equipment and process plant made with few concrete tanks and basins the Marshall and Swift index works very well.

The use of the ideal index would mean that at any time the cost of the motor would be identical. Consider 1976 as the comparison period of time. According to the MS index the prices over this 27-year period are:

$$\text{1949 data} = \$1350 \times \frac{485}{162} = \$4042$$

$$\text{1976 data} = \$3200$$

The difference is 26%. The MS index inflates 26% too high over this 27-year period.

According to the EPA index the results would be:

$$\text{1949 data} = \$1350 \times \frac{275}{66} = \$5625$$

$$\text{1976 data} = \$3200$$

The difference is 75%.

According to the ENR index the results would be:

$$1949 \text{ data} = \$1350 \times \frac{2494}{477} = \$7058$$

$$1976 \text{ data} = \$3200$$

The difference is 120%.

The MS index is supposed to represent construction in the process industry. The surprising feature is that the index includes labor and labor productivity and because of this should not be that pertinent to process equipment. Nevertheless, as the above test and similar evaluations done for all other types of process equipment illustrates that the MS index yields results that are within about 30% for all equipment except grinders.

For units where a large amount of concrete construction is used the MS index may not work as well. During 1966 to the present period there has not been sufficient difference between the main indices, illustrated in Table 10, to differentiate between the MS and ENR index based on the construction data we have available. This is primarily because of the scatter in the data. Our data from 1970 to 1976 suggest that the EPA values inflate too rapidly.

TABLE 10. COMPARISON OF THREE INDICES OVER THE 1966 TO 1976 PERIOD

Time	EPA	MS	ENR
1966	0.80	0.84	0.72
1970	1.00	1.00	1.00
Last quarter 1976	1.91	1.61	1.76
1976/1966	2.42	1.96	2.42

Any inflation index can only project costs from previous experience up to within about three months of the present time. How does one estimate for a project in the future? At the present time one does it very cautiously. The current guidelines seem to be to inflate at a

rate somewhere between 4% and 18% depending upon your estimate of how well the industry will settle down. During 1974 the annual inflation rate was about 18%, whereas in the 1960s the annual rate of inflation was about 4%. Currently the rate of inflation is between 6 and 8% according to the MS index. Values of the MS index and various rates of inflation extended into the future are shown in Figure 30.

Two weaknesses of all types of indices are:

1. new price lists change at discrete times whereas the indices show continuous variation with time.
2. inflation indices assume an average level of business for the vendor, contractor or consultant. If the contractor is underworked, then his bid will be below the average as shown by an inflation index and vice versa. Gerrard (1975) used time series analysis to study this problem and found that this influence can raise or lower the price by an average of 8%.

Sidenotes about Cost Correlations

Many do not believe cost correlations are worth developing because "the information becomes obsolete as soon as it is developed". We trust that the preceding discussion and illustrations have shown how reliable the inflation indices are and how useful data that are even 30 years old can be.

There are six important sidenotes about correlations that should be discussed. The first point is that the choice of the size parameter used in the cost correlation is of great importance.

We usually have three alternatives:

1. use the capacity or throughput; for example, the total flowrate of liquid waste to the treatment plant, as has been used in Figures 3 to 12.
2. use some engineering design parameter.
3. use some esoteric cost-contributing factor that gives a very accurate relationship between cost and size but which can be determined only from the supplier.

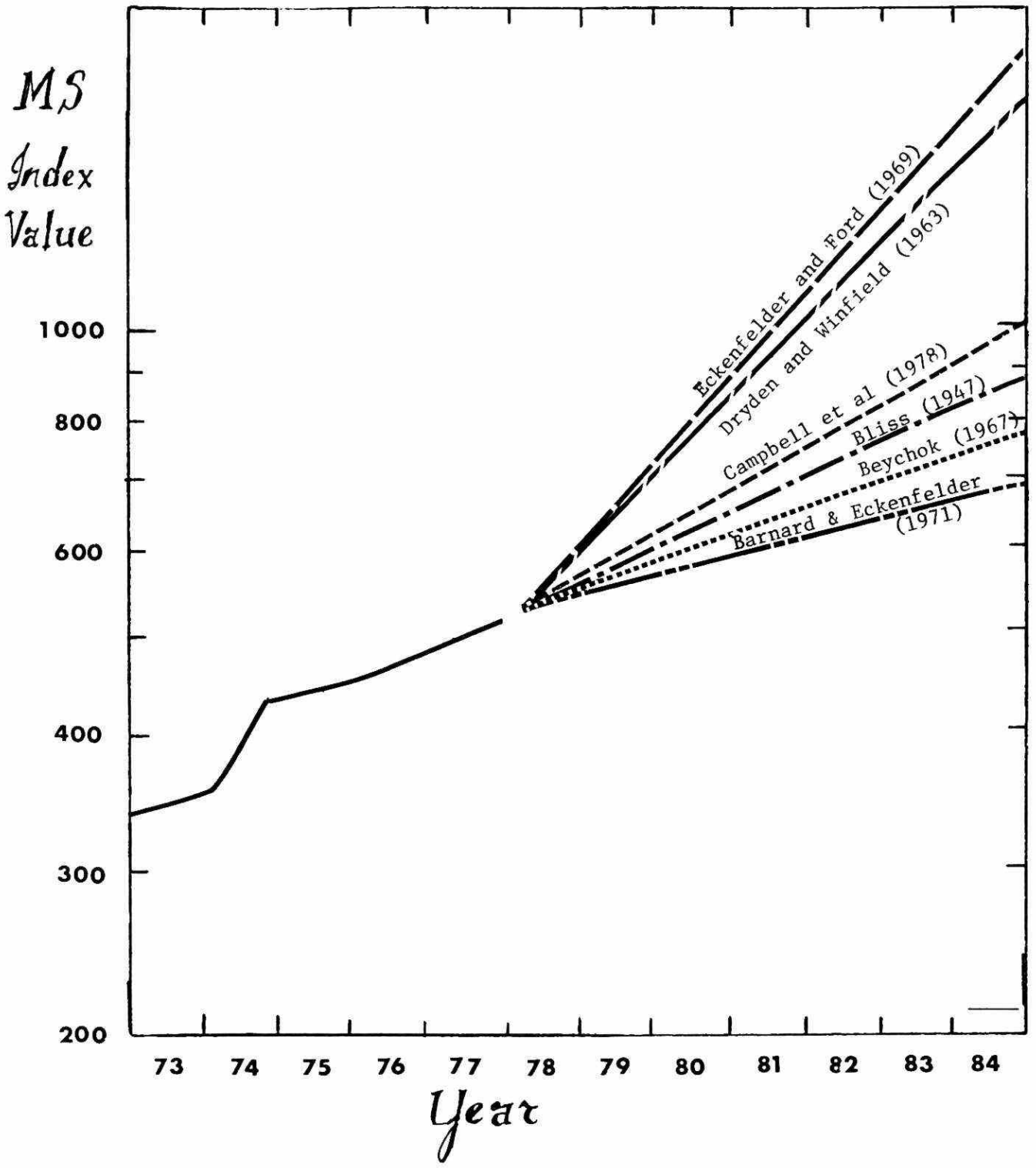


FIGURE 30. TRENDS IN THE MARSHALL AND STEVENS INFLATION INDEX

For non-engineers, the throughput capacity is the ideal correlating parameter. This gives us a cost estimate without needing to know anything about the process. Such correlations are based on "normal conditions" and "normal engineering" design practice; the answers will be the least accurate.

Engineers prefer to use correlations based on a design size parameter. Since, for example, we design thickeners on an overflow-rate basis we would want to use horizontal cross sectional area as the cost correlating parameter. Such parameters are use mainly in Figures 15 to 29. Such correlations are usually accurate to within $\pm$ 20%. Sometimes we have difficulty finding a single parameter that is important so we may choose a more complex function. For example, for pumps we may choose $(\text{head})^N$ $(\text{capacity})^M$ where N and M may be integer or fractional numbers.

Sometimes we seek more accuracy and just cannot find anything that seems reasonable in the previous two categories. Such happened with the belt filters shown in Figure 22. One might consider dry solids capacity or total belt effective filter area, or total equivalent vacuum filter area. Instead we elected to correlate in terms of the belt width. One would have to consult the supplier to translate "belt" width into the engineering numbers we understand. From such consultation we might discover that a $1\frac{1}{2}$ m belt is equivalent to about a 600 ft^2 capacity rotary vacuum filter and for our solids capacity the yield is about 4 lbs/ft^2h.

For centrifuges, for example, we could use the liquid or solids handling capacity, the drive horsepower, the Σ factor or filtration area, and the diameter of the centrifuge. These parameters represent all three classes of correlating parameter.

The second sidenote is that we should note on our correlations the "size range". This tells us the smallest and largest sizes that the equipment is usually made in. The third sidenote is that all correlations have some error.

The fourth sidenote is the misconception that published data are better than the internally generated information. In some circumstances this could be true, but in general it is not. Yet, we have found great

reticence on the part of many engineers to accept the cost data generated within the company. If we feel dissatisfied with the cost data generated inside our company then we should talk to those cost engineers. Maybe they are generating parameters that are of no use to us; if the information is misleading the cost engineers should be told.

The fifth sidenote is that cost data are not easy to locate. We can usually locate plenty of data for the usual pieces of equipment. However, often we have difficulty locating data for special designs. Hence, we need to collect a variety of data from which we build up the costs for the unique equipment we wish to use.

The final sidenote is that often a piece of equipment sounds too complicated for us to extract a simple cost. In reality certain variations on the basic unit make a very small change in the order of magnitude cost. Yet, when we are struggling trying to screen out the weaker candidates it is easy for us to become sidetracked into thinking that a detailed design is required before a decision is made. For example, on one unit we need a gear reducer. Upon contacting a supplier we soon began to believe that we needed to know the reduction ratio, whether we needed heavy duty service or not, whether the configuration was to be concentric, in-line or perpendicular and single or double reduction. Some sample cost data representing these different situations are given in Figures 31 and 32. However, once we had these data we were able to discover that a size parameter of (Input drive power at 1800 rpm) x (nominal reduction ratio)$^{0.5}$ reduced all the data (except single reduction 20/1 to 5/1) to a single, reasonable correlation. This is illustrated in Figure 33.

Consider now several examples of how the data reported in Figures 15 to 29 were obtained. Specifically consider the background for the data in Figure 16.

Gravity settlers are used to separate solids from liquids to yield a clear liquid overflow or to yield a thickened solids underflow. The basic unit is usually a cylindrical tank, with side walls 7 to 14 ft. high, open at the top, and the materials of construction can be carbon steel or concrete. Sometimes rectangular basins are used.

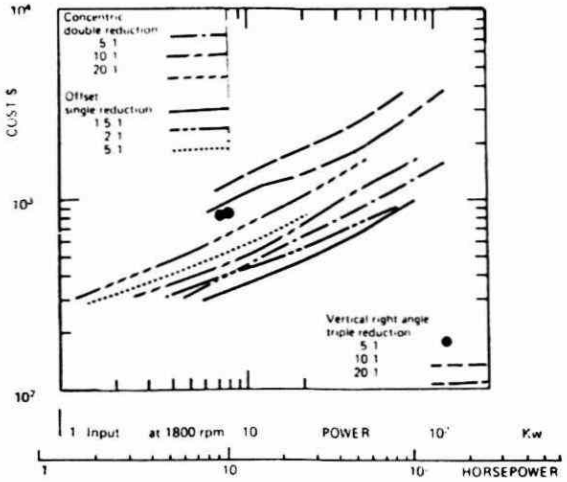


FIGURE 31. GEAR UNITS, HEAVY DUTY. FOB SUPPLIER EXCLUDING MOTOR AND LUBRICATION SYSTEM

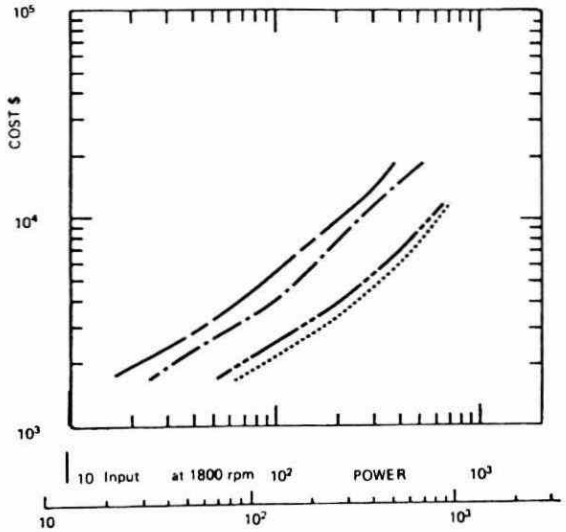


FIGURE 32. GEAR UNITS, HORIZONTAL RIGHT ANGLE. FOB SUPPLIER EXCLUDING MOTOR AND LUBRICATION SYSTEM

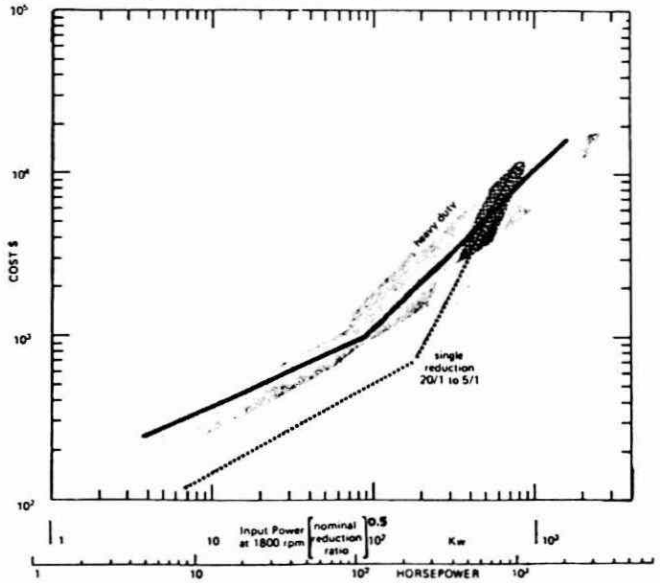


FIGURE 33. GENERALIZED CORRELATION FOR GEAR UNITS. FOB SUPPLIER EXCLUDING MOTOR AND LUBRICATION SYSTEM

The capital cost of the basic tank is given in Figures 34 and 35 correlated in terms of the total liquid volume and the horizontal cross-sectional area for carbon steel units. These are FOB and exclude painting. Painting would add about 20% to the FOB cost. For concrete tanks, a reasonable value is $135 to $200 (1970) per cubic yard of installed reinforced concrete. This includes all the labor and materials associated with installing the concrete. Alternatively, estimates of concrete basins suitable for clarification or thickening are given in Figures 36 and 37.

For clarifiers, a central rake mechanism, weirs and baffles and a skimming unit need to be installed. The FOB cost for an unpainted carbon steel unit including drive, access platform, central shaft and bridge but excluding the inlet pipe and overflow launders is given in Figure 38. These prices are about 80% for the central rake mechanism, 5% for the skimming unit and 15% for weirs and baffles. Painting (sandblasting combined with two-coat epoxy painting) will increase the price by 20%. Installation costs for this unit are about 35%. The details of the mechanism configuration are summarized in Table 11. In Figure 38, there seem to be two models being supplied with different costs for each model. For sludge thickeners, a larger motor is used for the drive; pickets are installed on the scraping arm, and there is no scum skimmer. The net effect on the total cost of the installed unit is to increase the price by approximately 10%. The total installed cost for clarifier basins with no central rake mechanism but including baffles, skimmer and screen box are given in Figure 39. The current data agree with the Dahlstrom and Cornell correlation. From Figure 38 and the approximate component breakdown and installation factors, an estimate of clarifier basins with central rake mechanisms can be made. The costs of such units are given in Figures 40 to 45.

Trying to discover the consistent trends in these data has been a challenge. The data in Figure 40 are for municipal installations where concrete has been used throughout and where the concrete has not just been needed for the clarifier basin. The current data for such conditions agree with the many consistent correlations, although another set of current data show higher costs for the smaller sized unit. As a check, many data

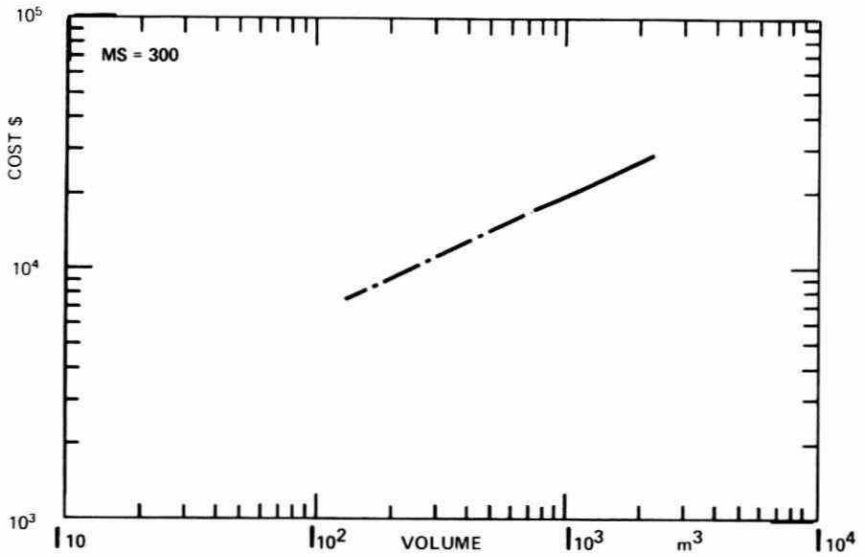


FIGURE 34. SEDIMENTATION TANK, CARBON STEEL TANK ONLY EXCLUDING INTERNALS, AND PAINTING. FOB

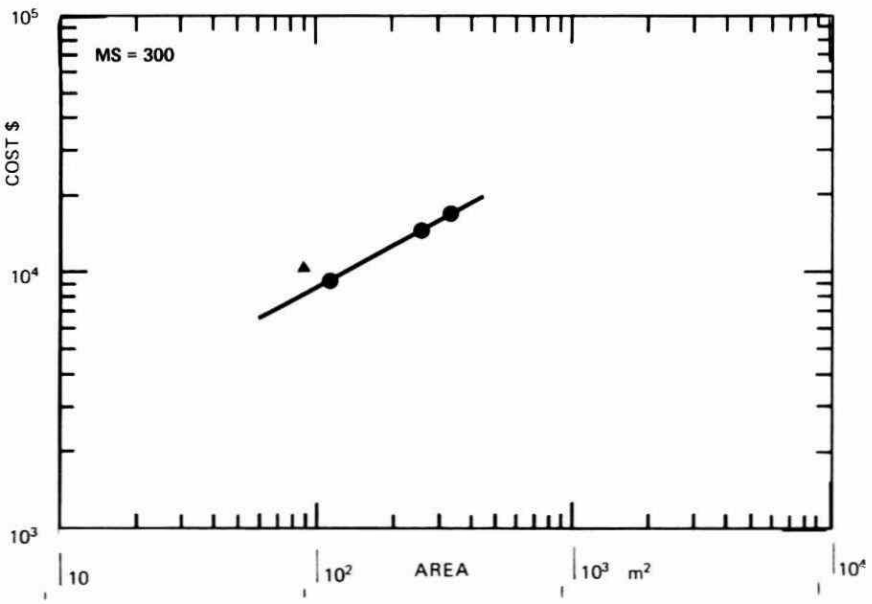


FIGURE 35. SEDIMENTATION TANK, CARBON STEEL TANK ONLY EXCLUDING INTERNALS AND PAINTING. FOB.

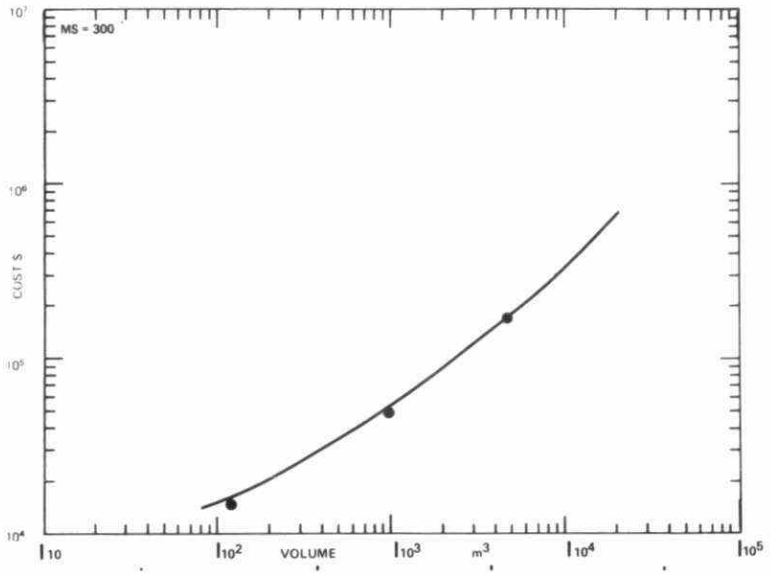


FIGURE 36. GRAVITY CLARIFIER/THICKENER BASIN ONLY - INSTALLED REINFORCED CONCRETE EXCLUDING EARTHWORK AND MECHANISM.

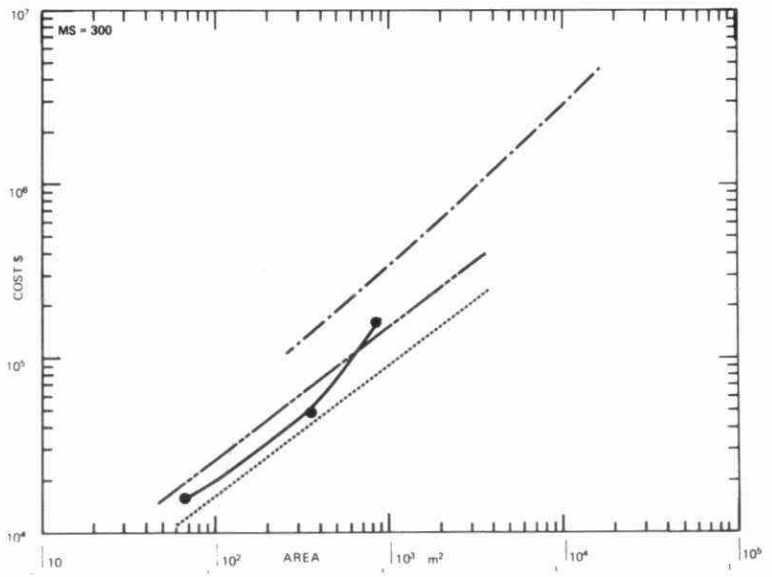


FIGURE 37. CONCRETE SEDIMENTATION BASIN ONLY. INSTALLED EXCLUDING EARTHWORK AND MECHANISM.

estimates for 4.3 m depth with
0.3 m floor thickness
0.45m wall thickness
Blecker et al (1974) for 5.2 m
depth aeration basin.

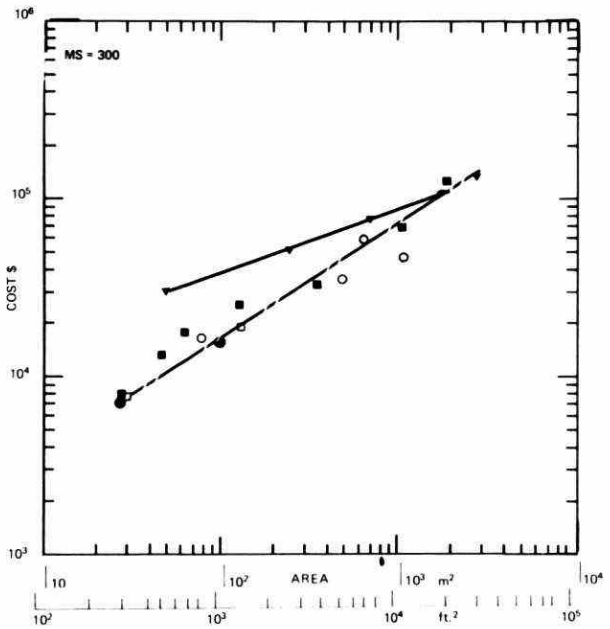


FIGURE 38. INTERNALS FOR A GRAVITY SETTLER: CARBON STEEL, INCLUDING MECHANISM, SURFACE SKIMMERS, DRIVE, MOTOR, ACCESS PLATFORM, CENTER SHAFT, BRIDGE, RAKE, SCRAPING ARMS. FOB EXCLUDING INLET PIPE AND OVERFLOW LAUNDERS

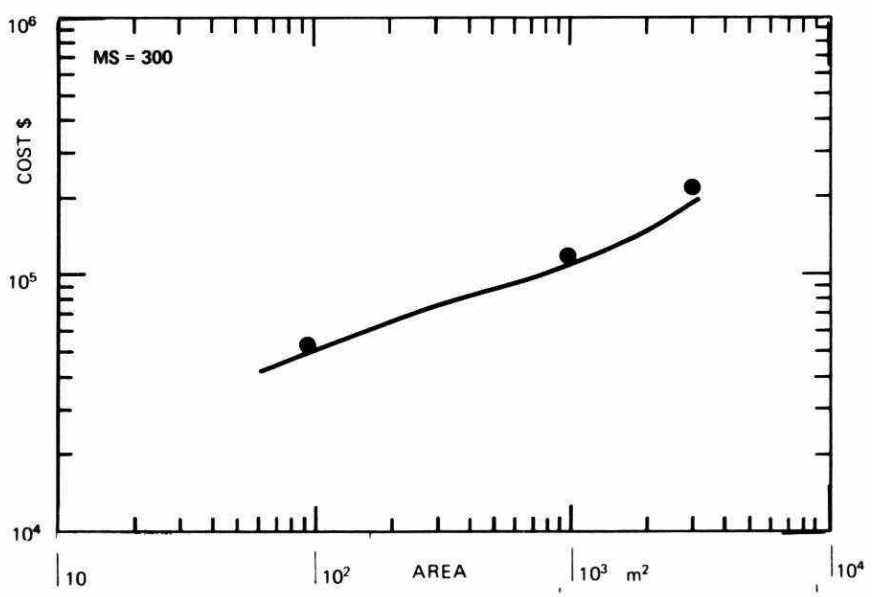


FIGURE 39. GRAVITY CLARIFIER - NO CENTRAL DRIVE OR RAKE INCLUDING BAFFLE, SKIMMER, SCREEN BOX, CONCRETE SIDES AND BOTTOM. INSTALLED INCLUDING NORMAL ERECTION AND SITE PREPARATION EXCLUDED

Dahlstrom and Cornell, 1971

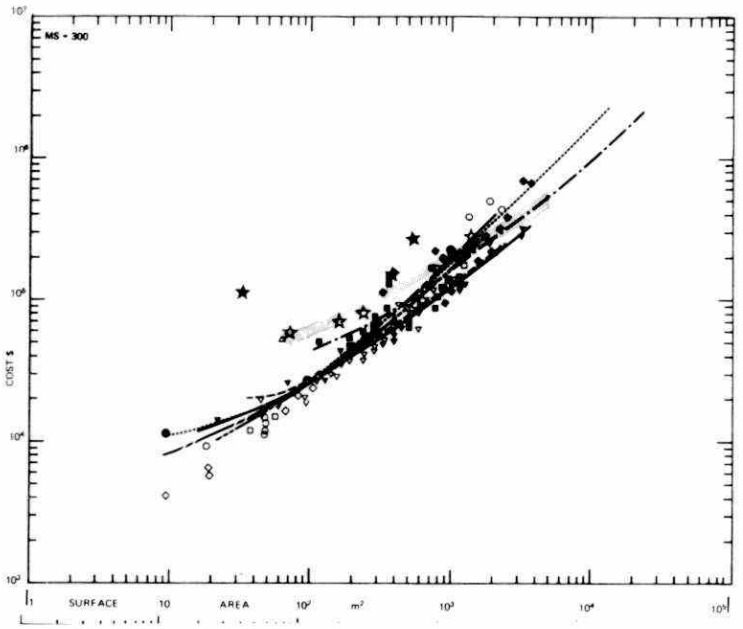
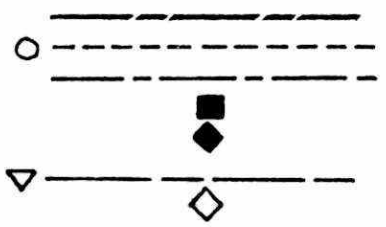


FIGURE 40. GRAVITY SEDIMENTATION FOR MUNICIPAL WASTEWATER TREATMENT. PRIMARILY CONCRETE BASIN WITH CARBON STEEL CENTRAL MOTOR-DRIVEN RAKE.

Primary Settler

Barnard and Eckenfelder, 1971
Burns and Roe, Inc., 1971
Patterson and Banker, 1971
    single basin
    two basins
DiGregorio et al, 1971
Russell and Axon as cited by Smith, 1968



Secondary clarifier

Barnard and Eckenfelder, 1971
Burns and Roe, Inc., 1971
Russell and Axon as cited by Smith, 1968, and Patterson and Banker, 1971
Personal Communications

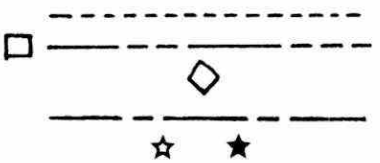


TABLE 11. CHARACTERISTICS OF CLARIFIER MECHANISMS

Area		Diam.		Depth		Rake drive power	
m^2	(ft^2)	m	(ft)	m	(ft)	kW	(hp)
29	(314)	6.1	(20)			0.56	(0.75)
66	(706)	9.1	(30)	4.	(13)	1.12	(1.5)
117	(1256)	12.2	(40)	4.3	(14)		
221	(2375)	16.75	(55)	4.3	(14)		
263	(2827)	18.3	(60)	4.3	(14)	1.12	(1.5)
358	(3848)	21.3	(70)	4.3	(14)		
410	(4418)	23	(75)	4.5	(15)		
527	(5675)	26	(85)	4.5	(15)		
730	(7854)	30	(100)	4.5	(15)	2.24	(3)
805	(8660)	32	(105)	4.9	(16)		
1140	(12,272)	38	(125)	4.9	(16)		
1430	(15,394)	43	(140)	4.9	(16)		
1642	(17,672)	46	(150)	5.2	(17)		
2919	(31,416)	61	(200)			5.6	(7.5)
6567	(70,686)	92	(300)			7.5	(10)
11674	(125,664)	122	(400)			11.2	(15)

are available for the cost of municipal units correlated in terms of the total flow of wastewater treated. Such data are given in Figure 41. Again, current data are in reasonable agreement except for the data of Velz (1948) and Okey (1972). Weber et al (1970) and Smith (1968) both report "bonded" costs that include engineering, interest and legal fees. To correct the data to exclude these allowances, the data are divided by 1.25, the factor they recommend. These data in Figure 41 can be cross-plotted on Figure 40 based on the design overflow rate for clarifiers in the range 500 to 1000 US gpd per ft^2. Such a cross plot gives results as are shown in Figure 42. For a comparison, representative data from Figures 40 and 41 are shown also. The difference must account for yard work, pumps, piping, electrical, instrumentation and all additional physical plant costs to convert an installed basis and mechanism to a working Battery-Limits installation. Such a cross plot emphasizes the need for care in interpreting data.

Figure 43 shows costs of clarifiers correlated in terms of the overflow cross-sectional area. Here, however, the data come from primarily process industry sources where the materials of construction could be carbon steel or concrete and where perhaps this is the only concrete pour on the site. The data of Raynor and Porter (1965), Chilton (1949), and Page (1963) in Figure 43 are in fair agreement. However, Dahlstrom and Cornell (1971) and their data of Figure 39 are three times higher for small scale units (3 to 10 m diam.), with the deviation becoming smaller as 30 m diameter unit is approached. The current data based on carbon steel installation and on concrete construction agree with Dahlstrom and Cornell; yet some of the data from Figure 40 agree with the lower cost predictions.

Eckenfelder et al's data for clarifiers for 'industrial applica - tions' in Figure 44 seem to show a compromise result between the data in Figures 40 and 43 for the small scale units, yet are significantly larger for the large diameter units. No explanation is given by these authors as to why this should be.

The cost of sludge thickeners has been reported. These are given in Figure 45. The more recent data of Adams and Eckenfelder (1975) agree with current data for installed carbon steel tanks, with a heavy duty central rake mechanism and with no scum removal system.

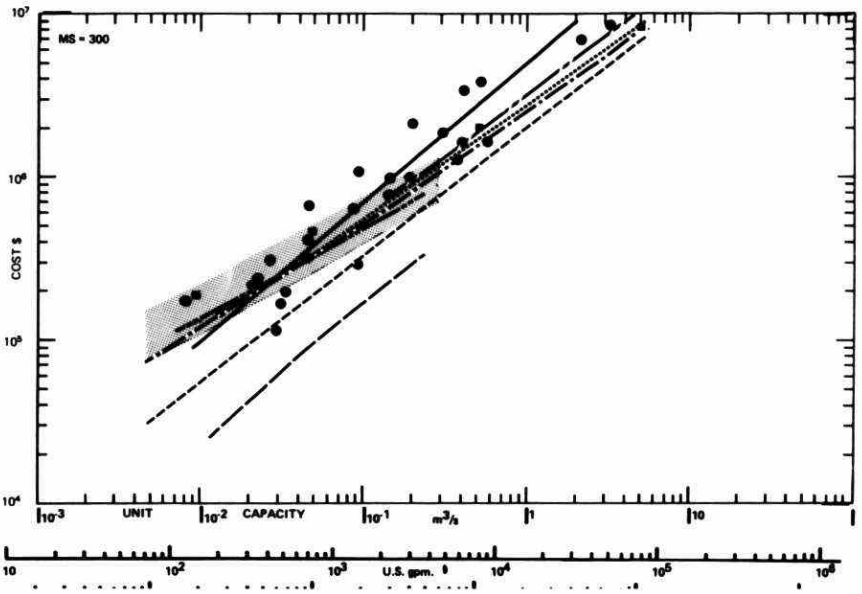


FIGURE 41. GRAVITY SEDIMENTATION. PRIMARY SETTLER FOR MUNICIPAL WASTEWATER TREATMENT. INSTALLED CONTRACT COST EXCLUDING ENGINEERING, LAND, LEGAL, FINANCING AND SLUDGE DIGESTION.

Weber et al, 1970 x $^{1}/1.25$, and Diachishin, 1957

Smith, 1968 x $^{1}/1.25$

Logan et al, 1962

PHS, 1964

Velz, 1948

Okey, 1972

Forbes and Witt, 1965

Ontario Ministry of Environment, 1965

Personal communication

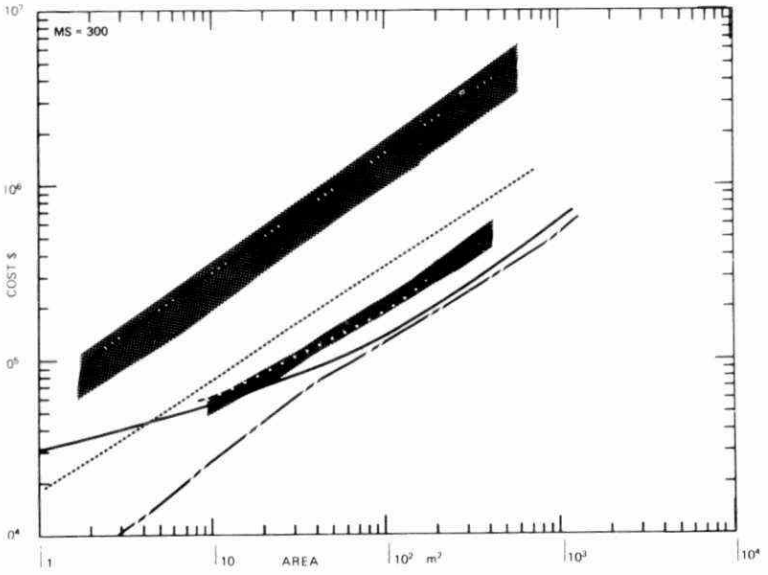


FIGURE 42. GRAVITY CLARIFIERS; INSTALLED INCLUDING BASIN AND CENTRAL MOTOR-DRIVEN RAKE MECHANISM

Eckenfelder and Ford, 1969

Weber et al, 1970

Dahlstrom and Cornell, 1971

Blecker et al, 1974

Personal communication (1977)
Calculations for 20 to 40 m^3/m^2 day
(500 to 1000 US gal/ft^2 day)

Raynor and Porter, 1966

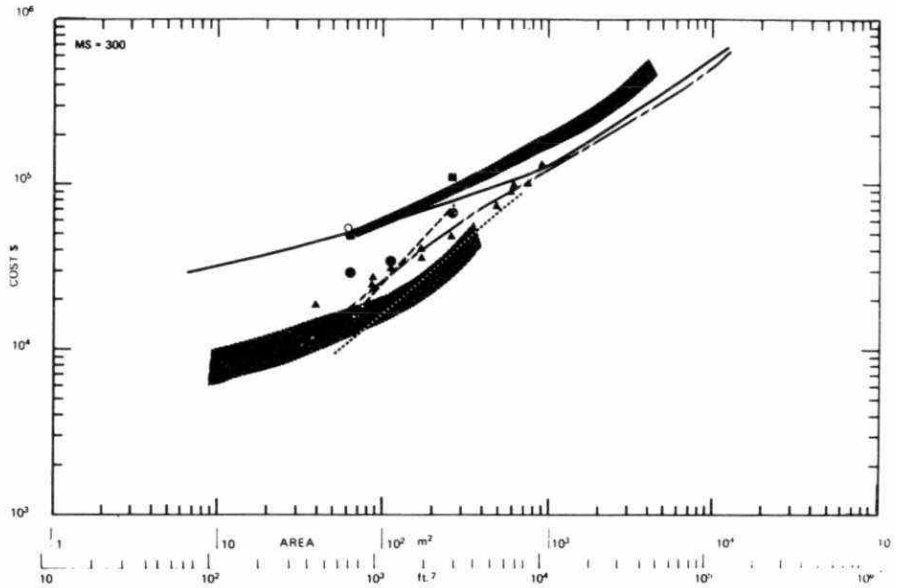
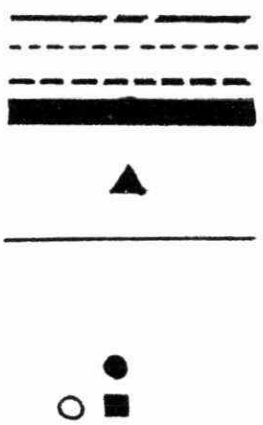


FIGURE 43. GRAVITY CLARIFIER/THICKENER INCLUDING BASIN, CENTRAL MOTOR DRIVEN RAKE, 3 m SIDE WALLS INCLUDING OVERFLOW LAUNDER, STANDARD DUTY RAKE FOR CONTINUOUS OPERATION WITH PERIPHERAL SPEED OF 7.5 m/min. INSTALLED INCLUDING OVERFLOW LAUNDER, CENTRAL ERECTED RAKE MECHANISM, MOTOR AND DRIVE EXCLUDING EXCAVATION, SITE CLEARANCE PIPING, FEED LAUNDER, TUNNELS, OVERFLOW PUMPS, CONTRACTOR'S FEES.

Raynor and Porter, 1965
Chilton, 1949 single compartment
double compartment
Page, 1963 delivered x 1.5
Gery, 1955 concrete including excavation, all mechanical equipment supports, weirs, erection wiring.
Dahlstrom and Cornell, 1971 concrete including nominal site preparation.
Personal Communication
c/s tank excluding pcd and electrical
FOB
Installed



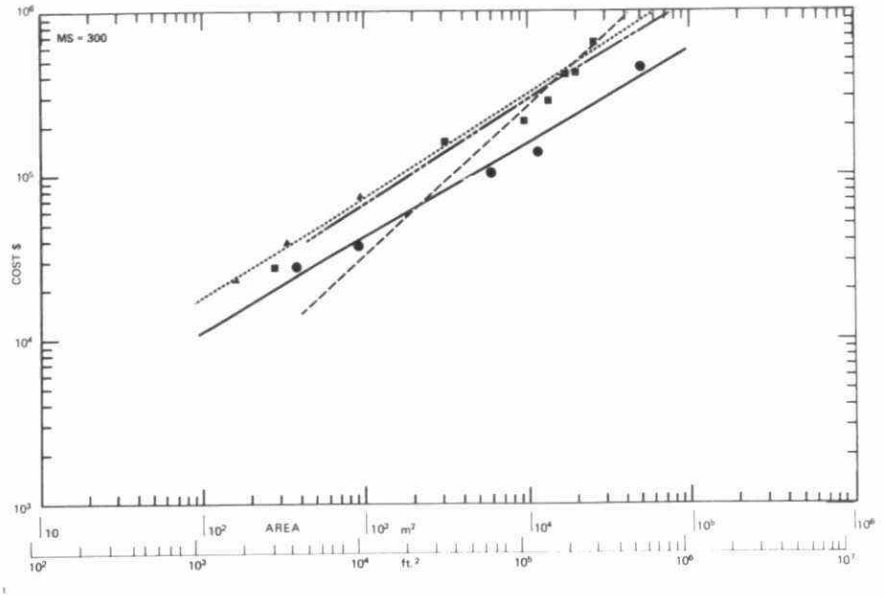


FIGURE 44. GRAVITY SEDIMENTATION - CONCRETE; FOR INDUSTRIAL APPLICATIONS WITH CENTRAL MOTOR-DRIVEN RAKE. INSTALLED INCLUDING OVERFLOW LAUNDER, CENTRAL ERECTED RAKE MECHANISM, MOTOR AND DRIVE EXCLUDING OVERHEADS

Primary settler

Eckenfelder and Ford, 1969 including overheads

Barnard and Eckenfelder, 1971

Eckenfelder and Barnard, 1971

Secondary clarifier

Eckenfelder and Ford, 1969 including overheads

Barnard and Eckenfelder, 1971

Eckenfelder and Barnard, 1971

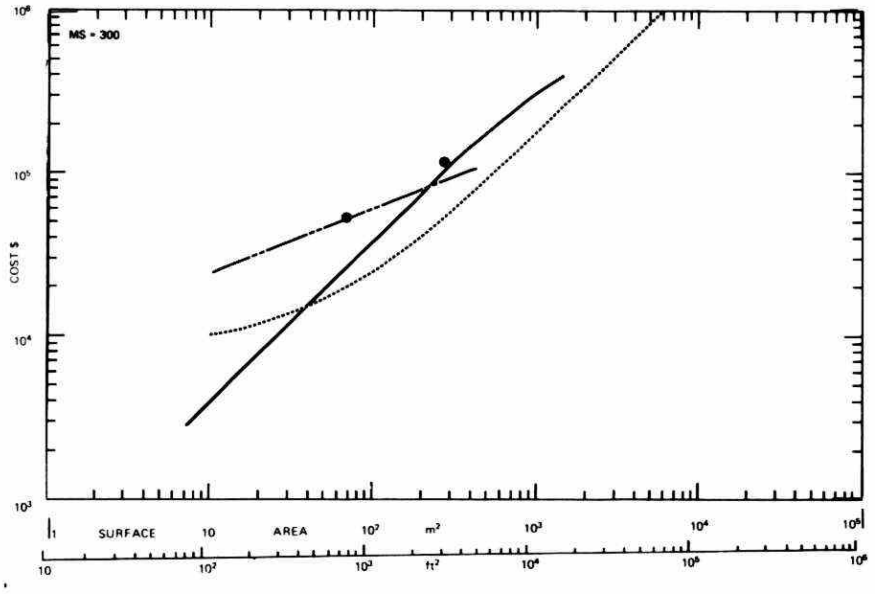


FIGURE 45. GRAVITY SEDIMENTATION FOR SLUDGE THICKENING. INSTALLED INCLUDING CENTRAL RAKE MECHANISM EXCLUDING ENGINEERING, CONTINGENCIES, FINANCING, LAND, LEGAL, FIELD EXPENSE

Barnard and Eckenfelder, 1971

Adams and Eckenfelder, 1975

from Figures 39 and 40

Personal Communication

More data were used in this analysis than were needed. However, the inclusion of these data allowed us to cross check the particular costs of interest.

Dissolved air flotation units can be used for two purposes: clarification of murky water and sludge thickening. The two uses have marked effects on the costs. The preferred correlating parameter is the horizontal cross-sectional area. The FOB cost of a shop fabricated carbon steel unit is given in Figure 46. For larger than 500 ft^2, a concrete basin is used. In Figure 46 for greater than 500 ft^2, two lines are shown. The lower line is for the carbon steel equipment only and excludes the cost of the basin whereas the higher cost point includes the basin cost. The factors that apply to the data are:

L + M = 1.50

including polymer addition = x 1.35 to 1.45 (x FOB data in Figure 46)

including building = x 1.70 (x FOB data in Figure 46)

The FOB cost of the polymer addition equipment so that the unit can be used for sludge thickening is given in Figure 47. The polymer addition equipment increases the FOB cost by about 35 to 45%. Turnkey plant costs for clarification and for sludge thickening, respectively, are shown in Figures 48 and 49, respectively. These current costs exclude the building. In Figure 48 the data of Forbes and Witt have been cross-plotted from Figure 12 based on an overflow velocity of 3500 US gal/ft^2 day.

The capital costs for rotary vacuum filters are usually correlated in terms of the filter area. However, two different areas are used and great care should be taken to identify which one is being used in any particular instance. The two areas used are:

1. the total drum area (π diameter of drum x width of drum). For a rotary vacuum filter this total drum area is used for filtering, washing and cake drying. This parameter is used primarily in the waste water area.
2. the effective filtering area which is only that portion of the drum used to form the filter cake. This, in turn, is

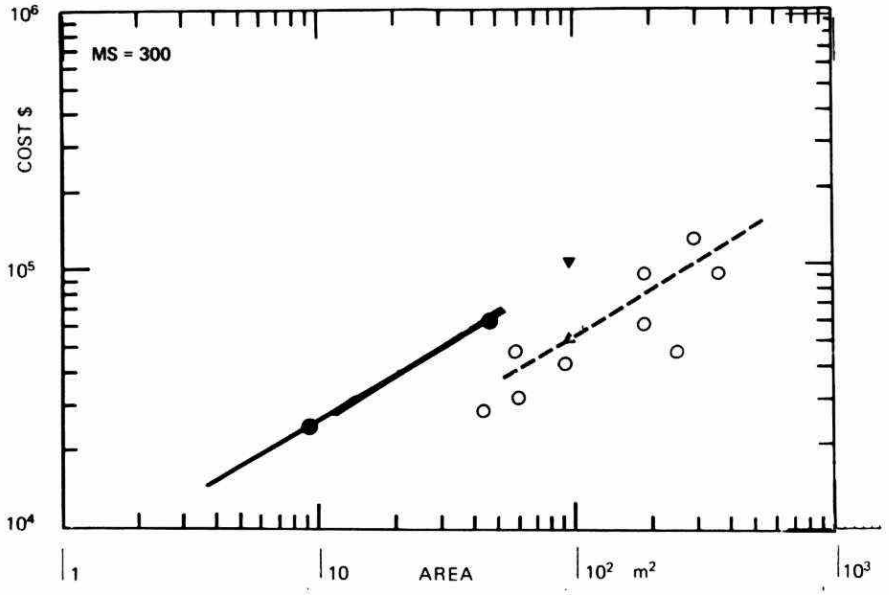


FIGURE 46. DISSOLVED AIR FLOTATION UNIT. COMPLETELY SHOP FABRICATED PACKAGE UP TO 50 m CARBON STEEL. FOB INCLUDING TANK, INTERNALS AND AUXILIARIES. EXCLUDING CONCRETE PAD, INFLUENT AND EFFLUENT LINES, CONTRACTOR'S FEES, INSTALLATION LABOR, BUILDING, TAX, POLYMER ADDITION EQUIPMENT.

for c/s equipment only ——————

excluding basin or tank

for c/s equipment plus concrete — — — — —

basin field fabricated

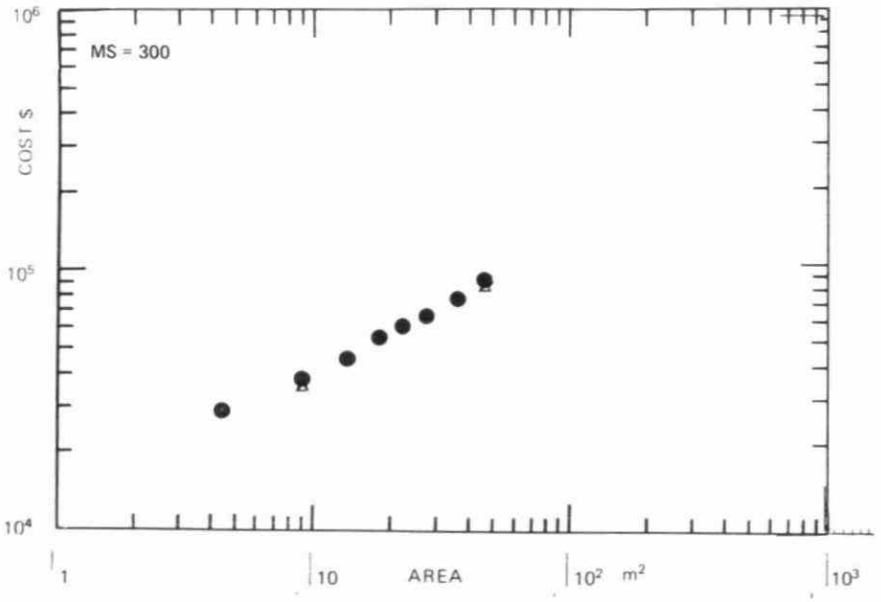


FIGURE 47. DISSOLVED AIR FLOTATION UNIT FOB PACKAGE INCLUDING ALL EQUIPMENT FOR POLYMER ADDITION. CARBON STEEL EXCLUDING CONCRETE PAD, INFLUENT AND EFFLUENT LINES, CONTRACTOR'S FEES, INSTALLATION LABOR, BUILDING, TAX

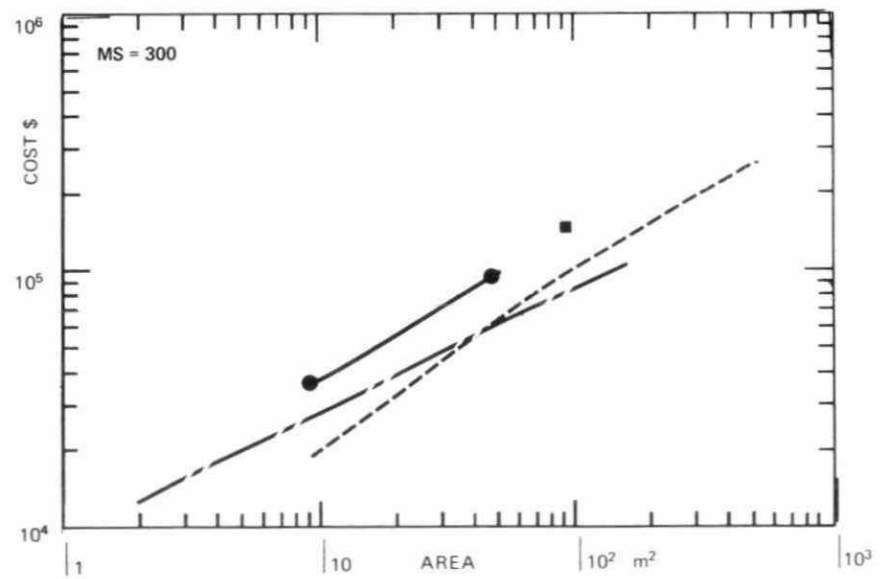


FIGURE 48. DISSOLVED AIR FLOTATION PACKAGE UNIT FOR CLARIFICATION. INSTALLED, TURNKEY UNIT EXCLUDING POLYMER ADDITION AND BUILDING.

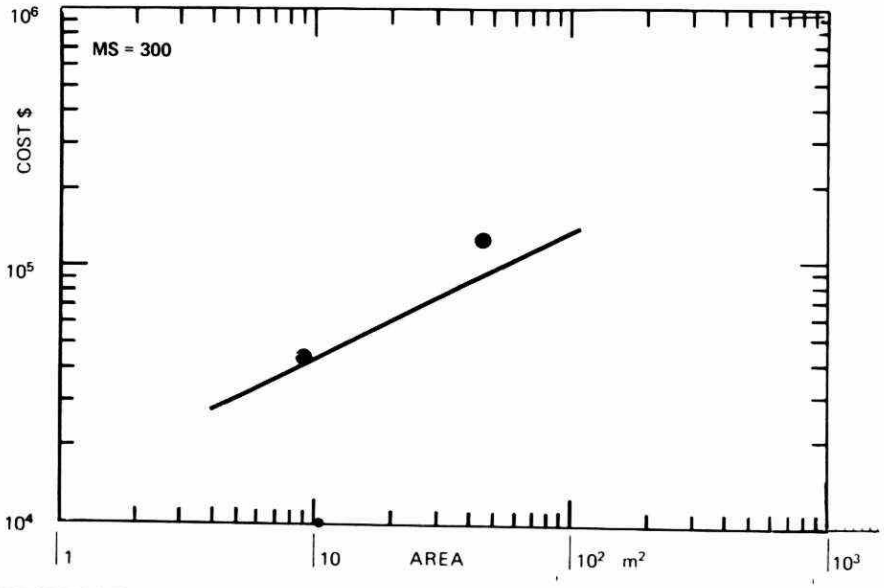


FIGURE 49. DISSOLVED AIR FLOTATION PACKAGE. CARBON STEEL. FOR SLUDGE CONCENTRATION. INSTALLED TURNKEY UNIT INCLUDING POLYMER ADDITION EXCLUDING BUILDING

McMichael, 1974 ——————
Personal Communication ●

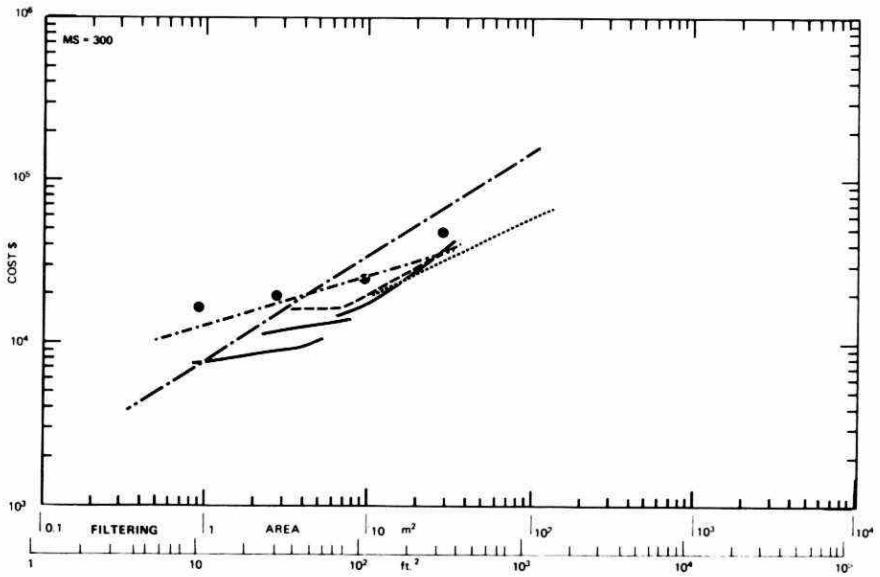


FIGURE 50. ROTARY DRUM VACUUM FILTER; CARBON STEEL WITH SWING TYPE AGITATOR, PANEL OR WIRE WOUND DRUM, WASH APPARATUS, VARIABLE SPEED DRUM DRIVE, TRUNIONS, STUFFING BOXES, SCRAPER DISCHARGE, MOTOR AND DRIVE, FOB EXCLUDING VACUUM SYSTEM AND VACUUM RECEIVER.

Guthrie, 1959 ——— — ———
Chalmers et al, 1955 ——————
Bliss, 1947 excluding motor based on total drum x 0.4 ——— — — — — —
Page, 1963 - - - - - - - - - - - -
Parkinson and Mular, 1972 total drum x 0.4 ——— — ———
Personal Communication ●

related to how much of the drum is submerged in the slurry. The usual values are 25 to 40%. Hence, here the effective filter area is 0.25 to 0.40 (total drum area). This form of correlation seems to have been used in the chemical engineering literature.

Often it is not clear as to which one is used.

The cost of a scraper discharge, rotary vacuum filter excluding the vacuum receiver and equipment, is given in Figures 50 and 51 correlated in terms of effective filtering and total drum area respectively. The current data are slightly above the earlier data. Precise specifications as to what the cost includes are not given for Guthrie's data. Nevertheless, the slope of his data does not agree with the current data.

Often the vacuum system, including the vacuum receiver and the vacuum pump unit, are given as part of the FOB package cost. Such data are given in Figure 52 correlated in terms of the total drum area.

For wastewater treatment applications the desired package often includes, in addition to the above, a belt discharge (instead of a simple scraper discharge), conditioning tanks for lime and for ferric chloride, feed pumps and an electric control panel. The costs for such components, FOB supplier, are given in Figure 53. This excludes the sludge pump and belt conveyor. Some cost factors that account for different variations of the rotary drum filter system are given in Table 12.

For installed units, the L + M factor is about 2.0 but this excludes housing, electrical, heating and ventillating.

The data are given in Figure 54 for the installed units. The specific conditions for each correlation are specified.

It should be noted that most of the cost comparisons needed in this paper were developed when the Canadian and United States dollars were at par. Most of the literature correlations were based on United States dollars; all of the current checks and data from suppliers and contractors were Canadian dollars. Because these currencies are not at par, care is needed in obtaining and using the correlations given in this paper and in obtaining information from suppliers. If the equipment is fabricated in Canada then the data quoted in these figures plus the MS inflation index should give reasonable estimates. If the equipment is

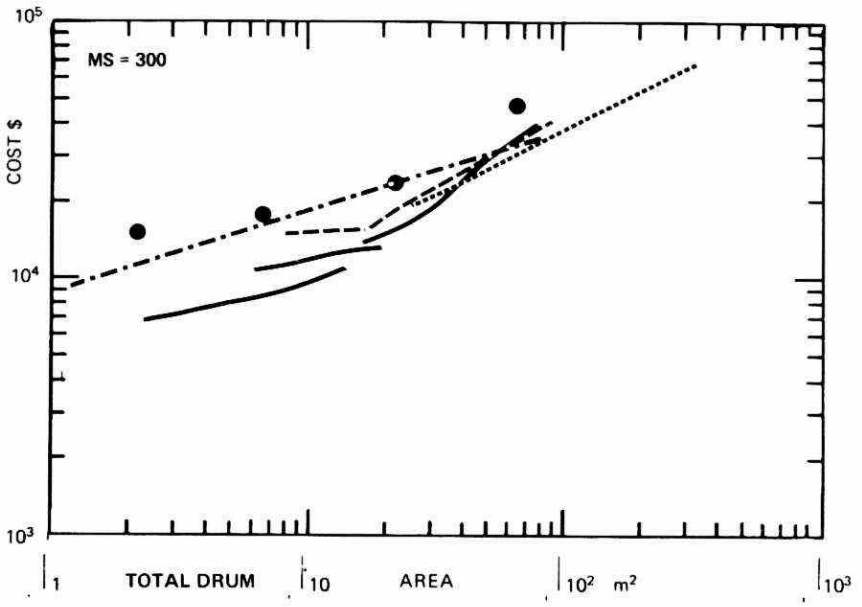


FIGURE 51. ROTARY DRUM VACUUM FILTER, CARBON STEEL WITH SWING TYPE AGITATOR, PANEL OR WIRE WOUND DRUM, WASH APPARATUS, VARIABLE SPEED DRUM DRIVE, TRUNIONS, STUFFING BOXES, SCRAPER DISCHARGE, MOTOR AND DRIVE, FOB EXCLUDING VACUUM PUMP AND VACUUM RECEIVER.

Chalmers et al, 1955 ——————

Chilton, 1949 excluding motor — — — — —

Page, 1963 - - - - - - - - - - -

Parkinson and Mular, 1972 — - — - —

Personal communication

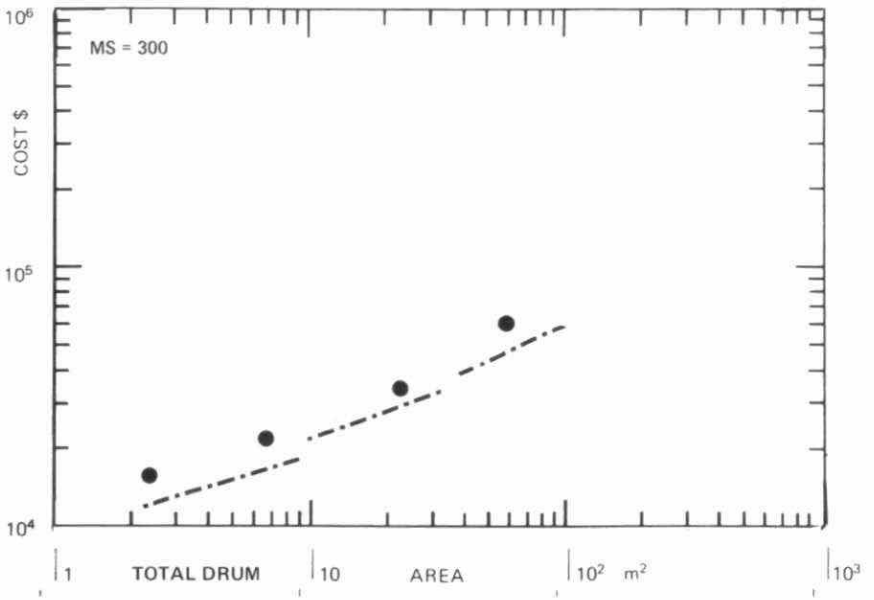


FIGURE 52. ROTARY DRUM VACUUM FILTER, CARBON STEEL WITH SWING TYPE AGITATOR, PANEL OR WIRE WOUND DRUM, WASH APPARATUS, VARIABLE SPEED DRUM DRIVE, TRUNIONS, STUFFING BOXES, SCRAPER DISCHARGE, MOTOR, DRIVE, VACUUM SYSTEM AND VACUUM RECEIVER. FOB.

Parkinson and Mular, 1972 ——————

Personal communication

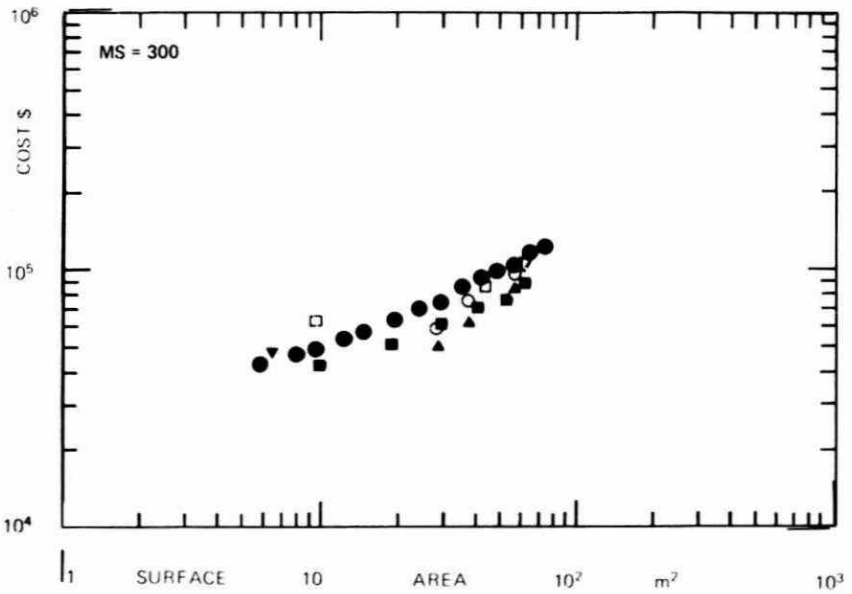


FIGURE 53. ROTARY DRUM VACUUM FILTER; COIL FILTER WASH APPARATUS, VARIABLE SPEED DRUM DRIVE, TRUNIONS, STUFFING BOXES, MOTOR, DRIVE, VACUUM PUMP AND RECEIVER, CONDITIONING TANK, $FeCl_3$ FEEDER, WET-TYPE LIME FEEDER, ELECTRICAL CONTROL PANEL. FOB EXCLUDING SLUDGE PUMP AND BELT CONVEYOR. TOTAL DRUM AREA

Personal communication

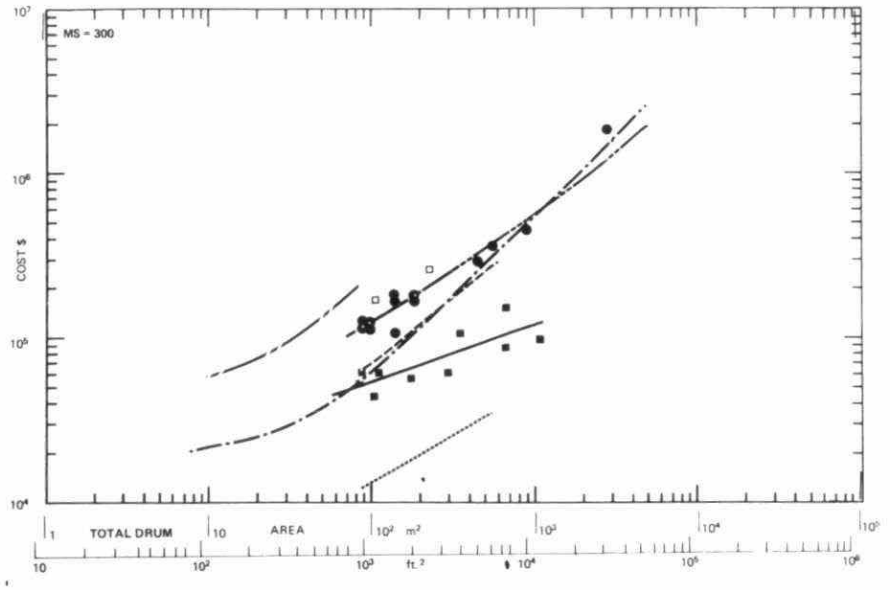


FIGURE 54. ROTARY DRUM VACUUM FILTER. COIL SPRING MEDIA AND TAKE OFF FOR SLUDGE TREATMENT

Page, 1963. FOB including vacuum unit

Patterson and Banker, 1971. Installed including piping, structures excluding electrical, heating and ventillating, actual installations estimates

Digregorio et al, 1968. Installed with all piping, pumps, vacuum equipment, excluding housing and structures.

Smith, 1968. Installed including housing.

Barnard and Eckenfelder, 1971. Excluding overheads.

Chow et al, 1968.

TABLE 12. COST COMPONENTS FOR DIFFERENT CONFIGURATIONS OF ROTARY VACUUM DRUM FILTERS

Basic scraper discharge unit including vacuum receiver and vacuum system c/s	1.00
Flexibelt or fabric belt take up	1.10 to 1.18
s/s Coil filter, special drum construction including some s/s and including cost of coils	Fabric belt unit x 1.15 to 1.20
Wastewater application including sludge pump.	Figure 48 x 1.15

imported, then the data quoted in these figures should be increased by the currency exchange rate plus the MS inflation index.

ESTIMATING THE OPERATING COST

As summarized in Table 1 the contributions that affect the operating cost are:

1. - the chemicals
2. - any credits for recovered materials
3. - the utilities (including steam, cooling water, fuel, electricity) U
4. - the labor cost (L) including the direct labor and supervision
5. - the maintenance materials, labor and supervision
6. - plant overhead
7. - depreciation and capital charges related to paying off the debentures issued to initially finance construction
8. - taxes
9. - insurance
10. - analytical services
11. - disposal costs.

Although we recognize that all these costs contribute, a wide variety of approaches have been taken to correlate and hence estimate these operating costs.

Annual Operating and Maintenance Costs

The most popular choice seems to be to report an annual cost (under the title of "Operation and Maintenance" and "Capital Charges"). The advantage of this system is that it is easy to record. The disadvantages are that we cannot separate the energy consumption and the labor contribution, we often do not know what all is included and we do not have a reliable method of scaling these costs from one year to the next. Under Operating and Maintenance expenses are normally included items 1 to 6; Capital Charges refers to item 7 and the Disposal Cost accounts for item 11. It is not always clear if items 6, 8, 9 and 10 are included.

Some sample results are shown in Figure 55. Sometimes these data are reported as money per unit volume of waste treated. Despite its frequency of use, we hope that this method is soon discontinued.

Annual Tabulated Costs

An improvement upon the annual O and M approach is to report the annual costs of most of the items 1 to 11. Yet this approach again suffers in that we do not know what the utility cost breakdown is and we cannot escalate in time with much confidence.

The Unit Usage Approach

The approach that has been used extensively in the process industry is the unit usage approach. In this method the actual, not dollar, usages of items 1 to 4 are reported. Thus, the weight of each chemical per 1000 m^3 treated, the kJ of electricity per 1000 m^3 treated, the tonne of fuel oil per 1000 m^3 treated, the operating man-hour or men per shift, the tons of solid for disposal - this is the form of the data. In this way the values are applicable regardless of the time. All we do is multiply by the current price of the chemicals, the utilities and operating labor to obtain the current cost estimates.

To date, some data have appeared for the man-hours of operating labor. Some samples are given in Figures 56 to 60.

Further analysis of the various items 1 to 11 indicates that most of the remaining items in the list can be correlated in terms of the fixed capital investment, I_F.

Thus,

Maintenance (including labor, materials) supplies	$\sim$	1 to 6% I_F
Capital charges	$\sim$	9% I_F
Taxes	$\sim$	4% I_F
Insurance	$\sim$	0.3% I_F

The supervision and overhead can be correlated in terms of the other cost items. In this way, a reliable, up-to-date cost can be determined. A summary of these relationships is given in Column 1 of Table 13.

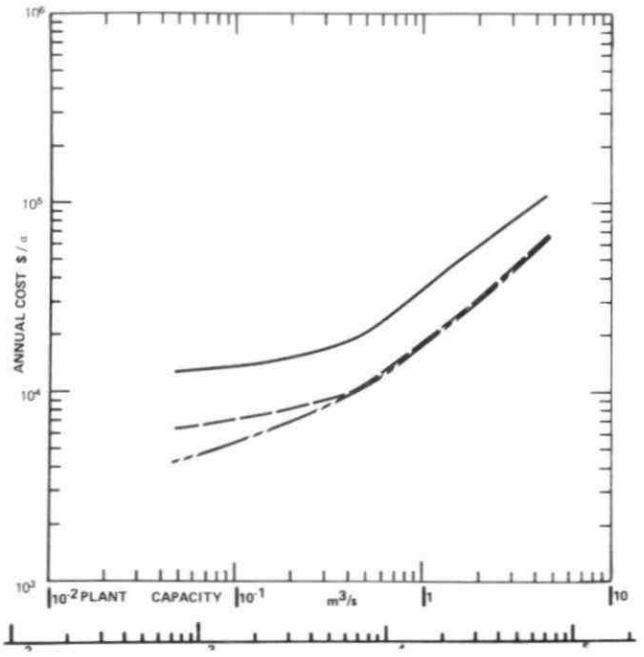


FIGURE 55. TOTAL ANNUAL OPERATING AND MAINTENANCE COST OF ANAEROBIC DIGESTORS EXCLUDING CAPITAL CHARGES

Culp et al, 1974 (mid 1974) ——————

Van Note et al, 1975 (mid 1973)
feed: primary and secondary conventional — — —
feed: primary and secondary with alum or Fe Cl_3 addition — — —
(Data NOT on the same time basis)

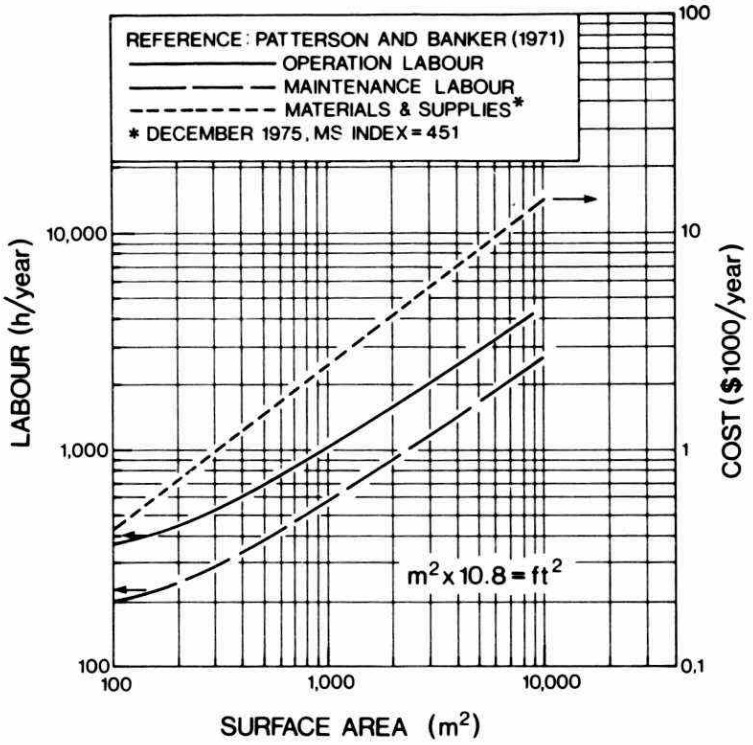


FIGURE 56. OPERATION AND MAINTENANCE COSTS - GRAVITY THICKENING

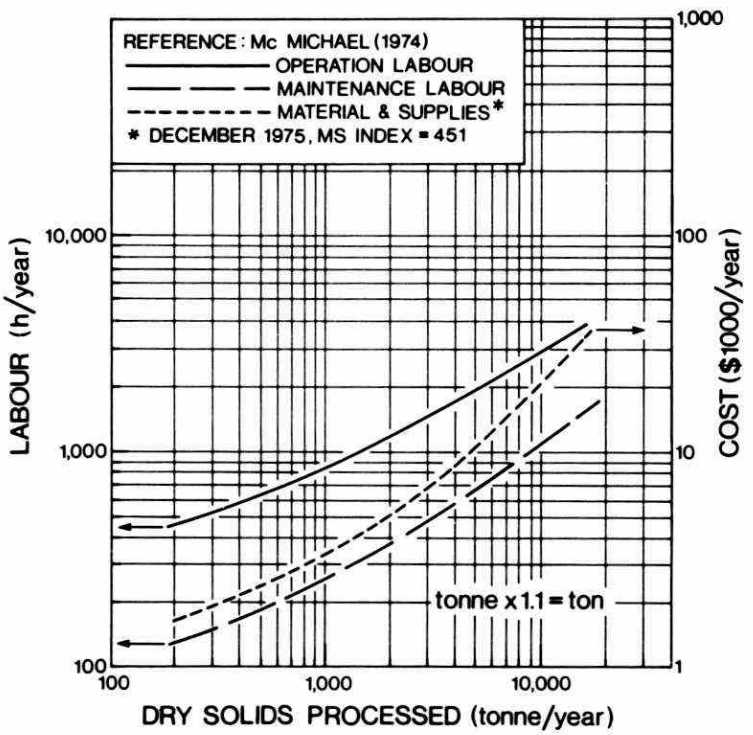


FIGURE 57. OPERATION AND MAINTENANCE COSTS - DISSOLVED AIR FLOTATION

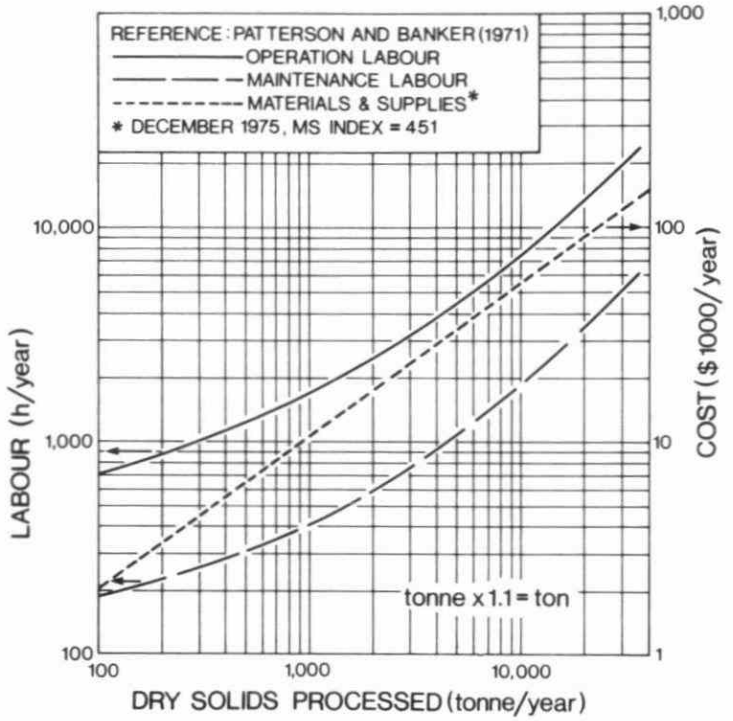


FIGURE 58. OPERATION AND MAINTENANCE COSTS - SOLID BOWL CENTRIFUGATION

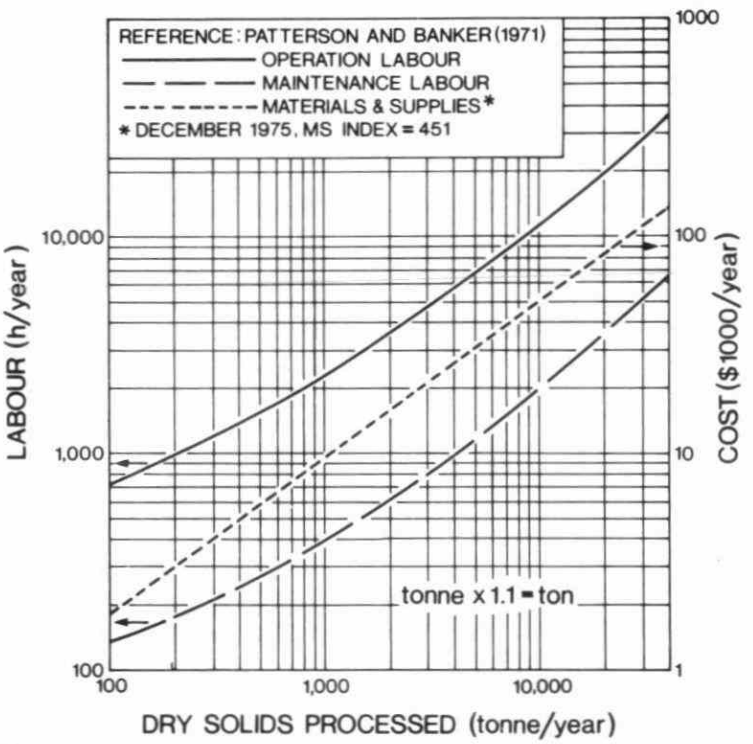


FIGURE 59. OPERATION AND MAINTENANCE COSTS - VACUUM FILTRATION

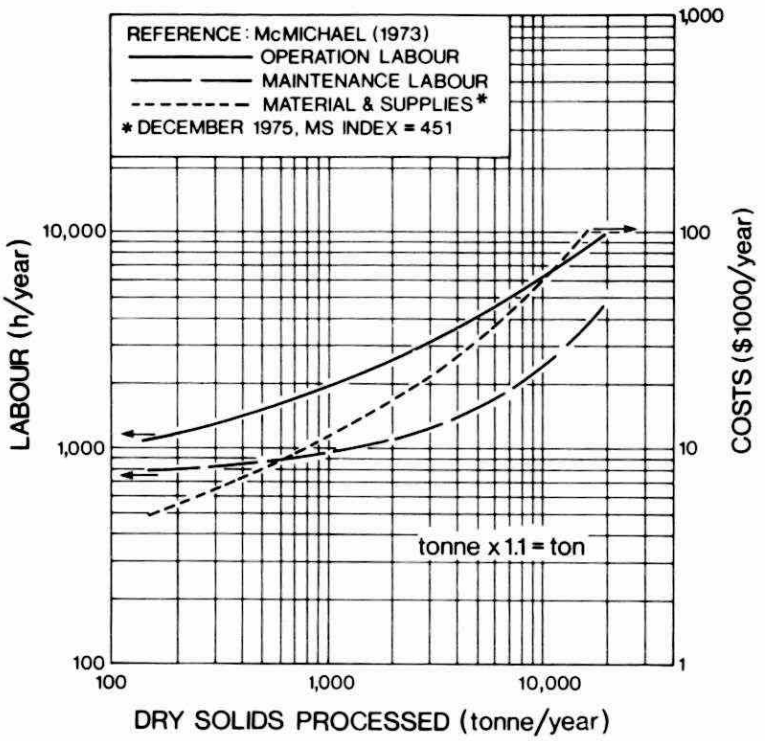


FIGURE 60. OPERATION AND MAINTENANCE COSTS - PRESSURE FILTRATION

TABLE 13. RELATING OPERATING COST COMPONENTS

Components	General (Ponder et al, 1976)	In Terms of I_F (Parker and Fong, 1976)
Chemicals (R) Byproducts (B) Utilities (U) electricity fuel		0.001 to 0.05
Labor direct (L) supervision	0.15 L	0.01 to 0.25
Maintenance (N) materials, labor	0.04 I_F	0.01 to 0.20
supervision, supplies	0.006 I_F	
Overhead Plant Payroll	0.5 (L + N) 0.20 (L)	0.02
Analytical services		0.004 to 0.01
Depreciation	-	-
Capital charges	0.09 I_F	
Taxes	0.04 I_F	
Insurance	0.003 I_F	
Disposal	-	-

SUMMARY

Methods for estimating the capital and operating costs for selected sludge treatment, dewatering and disposal systems were given.

For rapid estimates that are relatively inaccurate yet help to screen possible alternatives, the capital costs can be correlated in terms of the "capacity". Some data are given. However, for more accurate capital cost estimates a module or factor module method should be used. Details are given of how this method works, and data are given for sludge disposal equipment.

Some inflation indices are given and compared.

Details of methods for collecting and interpreting reliable correlations are given.

Some alternative methods of estimating the operating costs are outlined.

ACKNOWLEDGEMENTS

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GUIDELINES FOR APPLYING FOR APPROVAL FOR SLUDGE UTILIZATION ON LAND

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INTRODUCTION

This paper will deal with the certification process associated with programs for the application of sludge on agricultural land. Although this has been a practice carried on in Ontario for a good number of years, it is only recently that the various operations are regulated by legislation and specifically through The Environmental Protection Act and regulations made under it.

In the past the application of sludge on land was primarily a program of disposal in which there was limited interest as to any benefit or damage that this may cause. Like any other operation, however, many concerns were expressed by our agricultural people concerning the indiscriminate dumping of this material and the resulting problems associated with soil pollution. When one recognizes the great variety of constituents that can be found in sewage sludges, there can be no argument that we must exercise as much care with the disposal of this material as we do with any other.

In order to understand what follows, it is necessary that we appreciate the objectives of the approval process. We can all agree that sewage sludge can be beneficial as well as harmful. The certification process as currently carried out by the Ministry of the Environment for sludge handling encourages as the prime alternative programs which make use of the benefits that can be derived from the sludge in terms of soil improvement and to do that in such a way as to minimize the harmful effects. It should be understood, of course, that sewage sludges can just as well be disposed of instead of utilized depending on the characteristics of the sludge in each particular case. It would seem obvious that, in this day of resource recovery, the prime emphasis on the certification process would be that of utilization so that we may derive benefits from this waste rather than going to the simple disposal operation.

LEGISLATIVE BASE

The regulation of sewage sludge is provided for under The Environmental Protection Act and Regulation 824 made under it. Under Part V of The Environmental Protection Act, Section 28(d),

> "waste" includes ashes, garbage, refuse, domestic waste, industrial waste, or municipal refuse and such other wastes as are designated in the regulations".

In Section 2 of Regulation 824, materials which are wastes under The Environmental Protection Act are defined and, as indicated in 9(a), this includes "processed organic wastes". These are defined in Section 1, 27(a), Regulation 824,

> "processed organic waste" means waste that is predominantly organic in composition and has been treated by aerobic or anaerobic digestion, or other means of stabilization, and includes sewage residue from sewage works that are subject to the provisions of The Ontario Water Resources Act".

It is interesting to observe that in this definition sewage sludge is only "processed organic waste" if it has been treated in some fashion or otherwise stabilized. This, of course, means that raw sludge, although a waste, is not eligible for use in the utilization program.

Having established that in fact sewage sludge is a waste under Part V of The Environmental Protection Act, reference can be made to the additional provisions provided to regulate its handling. Of interest, reference should be made to the definition of "waste disposal site" and "waste management system" as included in Section 28(e) and (f), E.P. Act, respectively. Under Section 31,

> "No person shall use, operate, establish, alter, enlarge or extend,
>
> (a) a waste management system; or
>
> (b) a waste disposal site,
>
> unless a certificate of approval or provisional certificate of approval therefor has been issued by the Director and except in accordance with any conditions set out in such certificate".

Under Section 32,

> "No by-law for raising money to finance any work under Section 31 shall be passed by the council of a municipality until a certificate of approval or a provisional certificate of approval has been issued therefor".

In Regulation 824, under Section 4, waste disposal sites have been identified and include, as provided for under 7(a), organic soil conditioning sites. Organic soil conditioning is defined in Section 1, 25(a) in Regulation 824 and means,

> "the incoporation of processed organic waste in the soil to improve its characteristics for crop or ground cover growth".

In summary therefore, it is a requirement of the legislation that programs developed for handling of sewage sludge and any site used for that purpose must be approved by the Ministry of the Environment.

There is also an important provision within The Environmental Protection Act under Section 33(a) and Section 33(c), which reads as follows:

33(a)(1) "Where the Director receives an application for a certificate of approval for the use, operation, establishment, alteration, enlargement or extension of a waste disposal site for the disposal of hauled liquid industrial waste or hazardous waste as designated in the regulations or any other waste that the Director ascertains, having regard to the nature and quantity of the waste, is the equivalent of the domestic waste of not less than 1,500 persons, the Director shall, before issuing or refusing to issue the certificate of approval, hold a public hearing".

33(c)(1) "Where the Director receives an application for a certificate of approval for the use, operation, establishment, alteration, extension or enlargement of

(a) a waste management system that does not include a waste disposal site referred to in Section 33(a); or

(b) a waste disposal site other than a waste disposal site referred to in Section 33(a)

the Director may, before issuing or refusing to issue the certificate of approval, hold a public hearing".

Under these sections, the approving Director is, in specific cases, required to hold a public hearing prior to making a decision on the application and elsewhere is given the discretion to hold a hearing if he deems that one is necessary. It is interesting also to observe the provisions in Section 33(b) which permits the Director, should an emergency situation exist, to approve of a facility or program without calling a public hearing. It is important, however, in these circumstances to note very clearly the conditions which must exist before an emergency situation can be considered.

Section 33(b) states:

> "Notwithstanding the provisions of Section 33(a), where, in the opinion of the Director, an emergency situation exists by reason of
>
> (a) danger to the health or safety of any person;
>
> (b) impairment or immediate risk of impairment of the quality of the natural environment for any use that can be made of it; or
>
> (c) injury or damage or immediate risk of injury or damage to any property or to any plant or animal life,
>
> and the emergency situation will be alleviated by the use, operation, establishment, alteration, enlargement or extension of a waste disposal site, the Director may issue a certificate of approval therefor without holding a public hearing".

One additional section is worth noting. Section 35(1) states:

> "Where a by-law of a municipality affects the location or operation of a proposed waste disposal site, the Minister, upon the application of the person applying for a certificate of approval for the waste disposal site, may, by a notice in writing, and on such terms and conditions as he may direct, require the Environmental Assessment Board to hold a public hearing to consider whether or not the by-law should apply to the proposed waste disposal site".

In this case, the Minister himself, and not the approving Director, has the authority to grant exemptions to certain municipal by-laws in order to facilitate the operation of these programs in cases when the municipality has legislated against this practice. Prior to

considering an exemption, it is important to note that he must first hold a public hearing.

CERTIFICATION PROCESS

Figure 1 is a flow diagram which attempts to explain the approval process associated with applications under Part V of The Environmental Protection Act. This process is applicable to any application made under The Environmental Protection Act. As noted on the exhibit, the applicant prepares his application including the supporting documents which are then forwarded to the Ministry of the Environment regional office. The purpose of this is to have our regional staff screen the application initially prior to its formal submission to the "Approving Director". When the regional staff are satisfied with the application, it is forwarded on to the Head Office, and specifically to the Director of the Environmental Approvals Branch. At this point, the "Approving Director" must determine whether or not a hearing is either mandatory or desirable. In the case where a hearing is not considered mandatory or desirable, the "Approving Director" is permitted to consider the submission and issue his decision without any further consultation. There is an important item, however, which may be involved with these applications and that is the by-law question. As has been indicated before, the applicant has the opportunity to request the Minister to review any such by-law which conflicts with his intentions and decide whether or not an exemption is warranted.

As indicated in the exhibit, the Minister is required to hold a public hearing prior to making any decision with respect to the matter.

The Minister's decision in turning aside a by-law is tantamount to setting aside the planning process and it can be appreciated that the Minister would choose only to make such a decision if in fact the particular application was essential to the proper management of the particular waste to be dealt with. In cases, he has required that prior to giving any consideration to the applicant's request, that the applicant first proceed to have the matter resolved through the provisions under The Planning Act. In this case, the applicant has the opportunity to make application to the municipality for a change in zoning and if

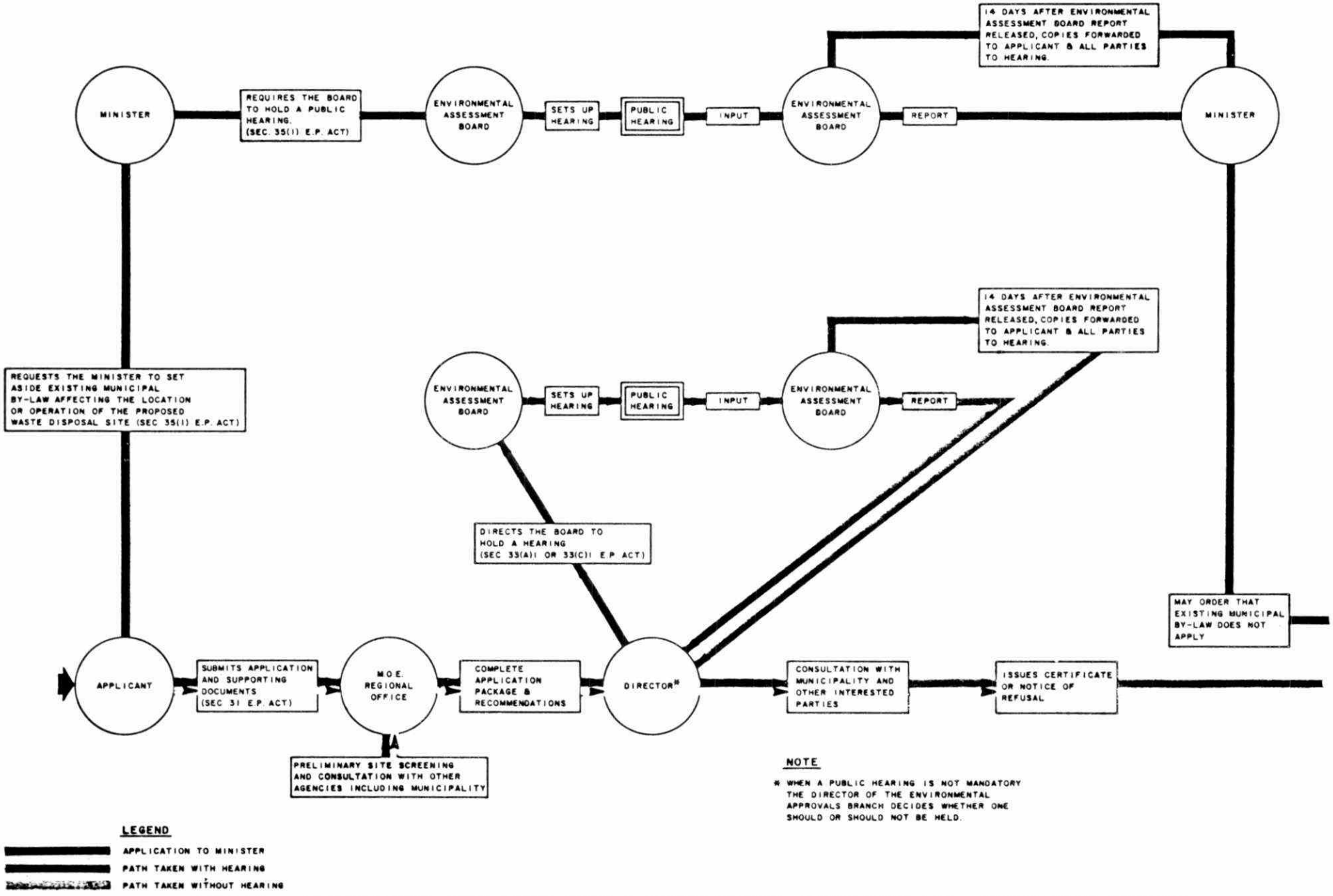
MINISTER
REQUIRES THE BOARD TO HOLD A PUBLIC HEARING. (SEC. 35(1) E.P. ACT)
ENVIRONMENTAL ASSESSMENT BOARD
SETS UP HEARING
PUBLIC HEARING
INPUT
ENVIRONMENTAL ASSESSMENT BOARD
REPORT
MINISTER
14 DAYS AFTER ENVIRONMENTAL ASSESSMENT BOARD REPORT RELEASED, COPIES FORWARDED TO APPLICANT & ALL PARTIES TO HEARING.
REQUESTS THE MINISTER TO SET ASIDE EXISTING MUNICIPAL BY-LAW AFFECTING THE LOCATION OR OPERATION OF THE PROPOSED WASTE DISPOSAL SITE (SEC 35(1) E.P. ACT)
ENVIRONMENTAL ASSESSMENT BOARD
SETS UP HEARING
PUBLIC HEARING
INPUT
ENVIRONMENTAL ASSESSMENT BOARD
REPORT
14 DAYS AFTER ENVIRONMENTAL ASSESSMENT BOARD REPORT RELEASED, COPIES FORWARDED TO APPLICANT & ALL PARTIES TO HEARING.
DIRECTS THE BOARD TO HOLD A HEARING (SEC 33(A)1 OR 33(C)1 E.P. ACT)
MAY ORDER THAT EXISTING MUNICIPAL BY-LAW DOES NOT APPLY
APPLICANT
SUBMITS APPLICATION AND SUPPORTING DOCUMENTS (SEC 31 E.P. ACT)
M.O.E. REGIONAL OFFICE
COMPLETE APPLICATION PACKAGE & RECOMMENDATIONS
DIRECTOR*
CONSULTATION WITH MUNICIPALITY AND OTHER INTERESTED PARTIES
ISSUES CERTIFICATE OR NOTICE OF REFUSAL
PRELIMINARY SITE SCREENING AND CONSULTATION WITH OTHER AGENCIES INCLUDING MUNICIPALITY
NOTE
* WHEN A PUBLIC HEARING IS NOT MANDATORY THE DIRECTOR OF THE ENVIRONMENTAL APPROVALS BRANCH DECIDES WHETHER ONE SHOULD OR SHOULD NOT BE HELD.
LEGEND
APPLICATION TO MINISTER
PATH TAKEN WITH HEARING
PATH TAKEN WITHOUT HEARING

FIGURE 1. APPLICATIONS MADE UNDER PART V ENVIRONMENTAL PROTECTION ACT - BASIC FLOW DIAGRAM

council cannot agree, he can appeal to the Ontario Municipal Board. It is the usual case, however, that the Ontario Municipal Board would be reluctant to deal with such an appeal unless it had been assured that the Ministry of the Environment was prepared to grant approval for the application.

In cases where the "Approving Director" has established that a hearing is mandatory or desirable, he then would direct the Board to hold a hearing and withhold any further action on the application until he has received the Board's report. It should be made clear that the report by the Environmental Assessment Board, which is the Board which would hear applications under Part V, E.P. Act, does not make decisions on the application but only makes recommendations to the "Approving Director". In the case where a hearing is mandatory or is desirable, and the applicant makes a request to have the Minister consider the by-law, hearings can be held concurrently. Administratively thereafter, the Minister, in these cases, would withhold his decision until such time as the "Approving Director" had made his decision as to the acceptability of the application.

MAKING THE APPLICATION

In accordance with Section 31, E.P. Act, the applicant is required to submit an application to the Ministry of the Environment for a Certificate of Approval for an organic waste management system if he intends to develop a utilization program on Ministry of the Environment standard application form, MOE 14218, including the supporting information form, MOE 14221. These forms are intended to ensure that all relevant information will be provided on the complete program and will give details on the source, collection, transportation, treatment and land intended to be used for this purpose. It must be noted that this is a "system" approval and all details must be complete on procedures and facilities which are to be employed even though this may include facilities which are not owned by the applicant.

At this point it should be pointed out that the Waste Management System Certificate gives authority to the holder to haul the material on public roadways. He is not required to obtain any further certification

on his hauling facilities. This Ministry does not issue any licences to haul wastes in Ontario except through the Waste Management System Certificate.

If within this program any land is to be used for any purpose, even though the applicant does not own it, certification of the particular site must be additionally sought from the Ministry in accordance with Section 31, E.P. Act. This will include sites used for interim holding facilities (storage lagoon) and sites used for the final application of sludge. In making applications for approval of sites, MOE forms #14210 and #14219 are to be used (appended).

In making application, it is useful at this point to highlight what significant information should be provided. Although the standard forms are intended to ensure all relevant information has been provided the applicant is free to supplement his submission by additional documents as he chooses. The following information is therefore the minimum which should be submitted.

(A) Organic Waste Management System

(1) the name of the Water Pollution Control Plant at which the sludge is produced;

(2) the quality and quantity of sludge to be utilized through this system;

(3) the number of acres of organic soil conditioning sites that are needed: (This is calculated on the basis of the sludge analysis and the Guidelines for Sewage Sludge Utilization on Agricultural Lands.);

(4) the capacity of the storage facilities that are required off site in order to store the sludge during inclement weather when it cannot be applied directly on land;

(5) the details of the trucking facilities which are to be used for transporting the material as well as the facilities for spreading.

Reference should be made to Section 14, Regulation 824, which states that:

> "The following are prescribed as standards for the operation of a waste management system:

1. All waste collection vehicles and waste carriers shall be so constructed as to enable waste to be transferred safely and without nuisance from storage containers to the vehicle.

2. Bodies of waste collection vehicles and waste carriers shall be so constructed as to withstand abrasion and corrosion from the waste.

3. Bodies of waste collection vehicles and waste carriers shall be leakproof and covered where necessary to prevent the emission of offensive odours, the falling or blowing of waste material from the vehicles or the release of dust or other air-borne materials that may cause air pollution".

(B) Organic Soil Conditioning Sites

(1) Identify the owner of the site and establish that the site is available.

(2) Give the exact location of the site:

1. this includes a site plan showing the farm boundaries within the Lot and Concession; and
2. a location plan, usually on a larger scale map showing the location of the actual organic soil conditioning site within the farm boundaries. The latter map eliminates any confusion as to where the sludge should or should not have been spread. (Most organic soil conditioning site plans now accent the actual site boundaries in some colour).

(3) Outline a brief operating program:

- this usually states the quantity of sludge that will be spread per acre and outlines during what months the spreading is to take place as well as in what manner the sludge is to be applied (e.g. simply spread or plowed under as well). We submit such an operating plan should be compulsory with all applications.

(4) Include notification, and preferably approval, from the municipality in which the site is to be located.

Reference should be made to Section 13a of Regulation 824, which states that:

> "The following are prescribed as standards for the location, maintenance and operation of an organic soil conditioning site:
>
> 1. The site shall be so located that it is an adequate distance from any watercourse, as determined by the land slope, to prevent direct surface drainage to the watercourse.
>
> 2. The site shall be at least 300 feet from the nearest individual dwelling.
>
> 3. The site shall be at least 1,500 feet from any area of residential development.
>
> 4. The site shall be so located that the maximum level of the ground water table at the site is at a sufficient distance below the surface to prevent the impairment of ground water in aquifers as determined by the permeability of the soil.
>
> 5. The site shall be at least 300 feet from any water wells.
>
> 6. No processed organic waste shall be applied to the site during any period in which conditions are such that surface runoff is likely to occur taking into account land slope, soil permeability and the climatic conditions of the area.
>
> 7. The site shall be established only on land that is, or is intended to be, used for pasture, fallow or the growth of forage crops
>
>   a. during the current growing season, or
>
>   b. where application of the processed organic waste is made sometime after the current growing season, to the end of the subsequent growing season.
>
> 8. Berms and dykes of low permeability shall be constructed on the site where necessary to isolate the site and effectively prevent the egress of contaminants."

What additional information should be submitted in any particular case depends on the specific difficulties and/or innovations which may be apparent. The best guide in making the submission is common sense rather than any religious dedication to completion of forms.

PITFALLS TO BE AVOIDED IN MAKING APPLICATIONS

In processing applications for this program a number of difficulties have arisen which has led to frustration for both the Ministry of the Environment and the applicant. The following are some examples:

1. Incomplete Analysis on the Sludge

   It is necessary, consistent with the guidelines, that the characteristics of the sludge are known before any management program can be selected. If for example, the sludge contains components which are harmful to the soil, care must be taken to ensure that the land receives only that amount which it is able to assimilate. In the extreme case it may be that a particular sludge is so contaminated that it would not be suitable for land application under any circumstances. In these cases obviously disposal programs should be searched out unless the characteristics of the sludge can be improved through sewer use by-laws.

   We recognize that the character of sludge varies considerably from year to year and even from day to day. Although a history of analysis would be beneficial, this is usually not available and some judgement is required on the matter when limited analysis is available.

2. Overcharging

   Either because insufficient land has been identified or the application or the rates have been ignored, the land is overcharged. Overcharging is inconsistent with utilization and cannot be approved. When overcharging, as determined by the guidelines, is proposed, this becomes a disposal program and certification should be sought on that basis.

3. Storage

   It is accepted that there are certain periods of the year when it is improper to place sludge on land either because of potential runoff or inaccessibility due to poor ground conditions. In this climate it

is becoming clear that interim holding facilities are necessary either at the plant or on other lands in order to ensure that proper handling methods are being employed. The applicant should discuss the need for storage and provide details on how it is to be accomplished in his application.

4. Municipal By-laws

It is important that the applicant determine early if any aspect of his program contravenes by-laws of the municipality. If it does he should be prepared to take concurrent steps to bring either his operation or the by-law into conformity one with the other. This will eliminate frustration later on and at least tell the applicant whether or not he wishes the Minister to review the matter. This can avoid hearings.

5. Lack of Field Control

Under the certification process, certificates are limited in time and require that these documents be reissued from time to time. It has been the practice, for example, that certificates be issued to cover the period of the contract and in these circumstances the sites particularly must be reconsidered for further use following the initial contract period. There is generally a lack of reports available to establish the amounts of sludge that have been applied on the land making it rather difficult to sanction continued use consistent with the constraints imposed by the guidelines. In one instance, to make matters worse, it was brought to the Ministry's attention that some Medical Officers of Health were permitting septic tank wastes to be disposed of on lands certified by the Ministry for sludge utilization.

6. Public Opposition

There have been cases where considerable opposition has been voiced by the general public to the spreading of sludge and that opposition has caused certain councils to pass by-laws and/or request that public hearings be held prior to certification. Where this has happened, there have been great delays and vicious attacks on both

parties. It is apparent that protection of the environment must be clearly demonstrated before concurrence can be expected by the public. The applicant must be sure when he reaches the hearing, if he is unfortunate enough to be in an area where one is demanded, to clearly demonstrate that his operations are environmentally safe and nuisance-free. The first step in achieving acceptance is strict adherence to the requirements of the legislation and guidelines. The Ministry of the Environment through our Regional Offices is prepared to support the applicant during these difficult exercises provided, of course, that he has paid great attention to the details of his program.

Perhaps as it should be, the operator in the business suffers considerably for past carelessness. One error in the discharge of his responsibilities will bring public wrath the next time around making it almost impossible to obtain further approvals to cover his continuing operations.

CONCLUSIONS

To summarize, the Ministry of the Environment has a legislative responsibility to ensure that the handling of sewage sludges is carried out properly and has accepted that the spreading of this material on land is a viable alternative provided care is taken to ensure benefits will be derived and soil damage prevented. It is not acceptable anymore to indiscriminately dump sewage sludges in uncontrolled amounts on lands which the operator may have access to.

It is intended through our certification process to pay stricter attention to the details of these programs and the Ministry will continue to reject those applications which are inconsistent with the objectives of the utilization program.

It will likely turn out as well that more and more programs will be subjected to public scrutiny and this will mean that the applicant will have to pay greater attention to the legitimate concerns as expressed through our hearing process. He will be aided, it is hoped, by the intentions of this Ministry to require that this operation be planned with full regard for the potential benefits and the harm it can create.

Ontario

Ministry of the Environment
Waste Management Branch

APPLICATION FOR A CERTIFICATE OF APPROVAL FOR AN ORGANIC WASTE SITE

FOR MINISTRY USE ONLY

File No. _____

IMPORTANT NOTE: THIS FORM MUST BE SUBMITTED THROUGH THE OFFICE OF THE REGIONAL WASTE MANAGEMENT ENGINEER. (INSTRUCTIONS ON REVERSE MUST BE READ BEFORE COMPLETING THIS FORM)

1. OWNER - APPLICANT
NAME
ADDRESS
TELEPHONE

2. TREATMENT PLANT SERVED
NAME
ADDRESS
TELEPHONE

3 a. SITE OWNER
NAME
ADDRESS
TELEPHONE

3 b. SITE LOCATION
DISTRICT, COUNTY - TOWNSHIP
CONCESSION NO. LOT NO.

4. ISSUE ☐ (IF REISSUE COMPLETE 5 AND 6)
REISSUE ☐

5. CERTIFICATE ☐ No. _____
PROVISIONAL ☐ Date _____

6. CHANGES IN SITE (IF APPLICABLE)

7. OPERATOR OF SITE
NAME
ADDRESS
TELEPHONE

8. TYPE OF SITE

- ☐ Organic Soil Conditioning Site
- ☐ Transfer Site (i.e. storage lagoon, etc.)
- ☐ Composting Site
- ☐ Other: _____

9. REMARKS

SUPPORTING INFORMATION FORM MUST BE ATTACHED

Dated this _____ day of _____ 19____

SIGNATURE OF OWNER - APPLICANT

MOE 14210 7/73

INSTRUCTIONS FOR A SITE APPLICATION

SECTION 1: The application for a Certificate of Approval shall be made by the person or the municipality responsible for the site and its operation in conformity with The Environmental Protection Act, 1971 and the Regulation. The applicant shall also be responsible for the particulars provided in the application and with the supporting information provided therewith. By signing the application, the applicant accepts all responsibilities as set out for the "Owner" or "Operator" in the relevant sections of The Environmental Protection Act 1971 and the Regulation.

SECTION 2: The name and address of the plant from which the processed organic waste will be received for this particular site.

SECTION 3: The owner of the actual soil conditioning site who may or may not be the same as in section 1 and the actual site location.

SECTION 4: The applicant shall check the appropriate square if the application is for an "Issue" , proceed to section 7 .

SECTION 5: This section is to be completed if either:

(a) A Provisional Certificate of Approval has already been issued and a Certificate of Approval is required or

(b) A Provisional Certificate or a Certificate of Approval has already been issued and a change in ownership is proposed or has occurred, or if significant alterations to the extent, use, or method of operation, of the system have occurred or are proposed.

SECTION 6: To be completed only when changes in use, ownership, or operation have occurred since the date of the original application or if changes are proposed in the immediate future.

SECTION 7: The operator means the person or municipality in occupation or having the charge of the soil conditioning site.

SECTION 8: This item shall be completed by checking the appropriate box in this item or writing in any other use of site.

Ontario

Ministry of the Environment
Waste Management Branch

SUPPORTING INFORMATION TO AN APPLICATION FOR APPROVAL OF AN ORGANIC WASTE SITE

FOR MINISTRY USE ONLY

AUTHORITIES CONSULTED

	Objection	No Objection		Objection	No Objection
SANITARY ENGG.	☐	☐	MUNICIPALITY	☐	☐
AMB	☐	☐	AGRICULTURE	☐	☐
MOH	☐	☐			

OTHER _____

INSPECTION RECORD FORMS ATTACHED	YES ☐	NO ☐
REGIONAL ENGINEERS REPORT ATTACHED	YES ☐	NO ☐
GROUND WATER MONITORING	YES ☐	NO ☐
SURFACE WATER MONITORING	YES ☐	NO ☐

1. OWNER - APPLICANT

NAME

ADDRESS

TELEPHONE

2. SITE LOCATION

DISTRICT, COUNTY - TOWNSHIP

CONCESSION NO. LOT NO.

GENERAL DESCRIPTION OF SITE (FIELD LOCATION, TOPOGRAPHY, ETC.)

TOTAL SITE AREA _____ ACRES	DISTANCE TO DWELLING _____ FEET
TOTAL USABLE AREA FOR WASTE DISPOSAL _____ ACRES	DISTANCE TO PUBLIC ROAD MEASURED FROM WORKING AREA _____ FEET
DISTANCE TO NEAREST WATERCOURSE _____ FEET	DEPTH TO WATER TABLE BELOW SURFACE _____ FEET
DISTANCE TO NEAREST POTABLE WELL WATER SUPPLY. _____ FEET	ON _____ (Date) 19____
DEPTH OF WELL NOTED ABOVE _____ FEET	

3. OWNER OF SITE

NAME

ADDRESS

TELEPHONE

NOTE: Proof of "Right of Use" must be attached if owner is not applicant.

4. EXISTING AND PROPOSED LAND USE

5. PLANNED TRAVEL ROUTES

6. ALTERNATE SITE(S) (Fields, Storage Tanks, Lagoons, Etc.)

7. THE FOLLOWING DOCUMENTS ARE ATTACHED:

(MUST INCLUDE TWO MAPS: 1 - SCALE MAP
2 - SITE LOCATION DIAGRAM.)

Dated this _____ day of _____ 19____

_____
SIGNATURE OF APPLICANT

Ontario

Ministry of the Environment

APPLICATION FOR A CERTIFICATE OF APPROVAL FOR AN ORGANIC WASTE MANAGEMENT SYSTEM

FOR MINISTRY USE ONLY

File No.

IMPORTANT NOTE: SUBMIT THIS FORM TO THE MINISTRY'S REGIONAL OFFICE. (INSTRUCTIONS ON REVERSE MUST BE READ BEFORE COMPLETING THIS FORM.)

1. OWNER - APPLICANT
NAME

ADDRESS

TELEPHONE

2. TREATMENT PLANT SERVED (ONE ONLY)
NAME

ADDRESS

TELEPHONE

3. ISSUE ☐
REISSUE ☐ (IF REISSUE COMPLETE 4 AND 5)

4. CERTIFICATE ☐ No.
PROVISIONAL ☐ Date

5. CHANGES IN SYSTEM (IF APPLICABLE)

6.

THIS SYSTEM INCLUDES ____ NUMBER ORGANIC DISPOSAL SITE (S)

APPLICATION (S) FOR APPROVAL ATTACHED ☐

PREVIOUSLY ISSUED CERTIFICATES OF APPROVAL FOR SITES. NUMBERS

7. OTHER FACILITIES

8. OPERATOR
NAME

ADDRESS

TELEPHONE

SUPPORTING INFORMATION FORM MUST BE ATTACHED

Dated this day of 19

SIGNATURE OF OWNER - APPLICATION

HEAD OFFICE COPY

Ontario

Ministry of the Environment

Waste Management Branch

SUPPORTING INFORMATION TO AN APPLICATION FOR AN ORGANIC WASTE MANAGEMENT SYSTEM

FOR MINISTRY USE ONLY

File No.

AUTHORITIES CONSULTED:

	YES	NO		YES	NO
SANITARY ENGG.	☐	☐	MUNICIPALITY	☐	☐
AMB	☐	☐	W.P.C.P. OPERATING AUTHORITY	☐	☐
MOH	☐	☐			

OTHER

REGIONAL ENGINEERS REPORT ATTACHED ☐

1. Owner — Applicant

NAME

ADDRESS

OWNER

PHONE

2. Source of Sludge

PLANT NAME

ADDRESS

OWNER

PLANT TYPE EST. VOL. HANDLED

3. Proposed Contract Dates

COMMENCEMENT | TERMINATION

4. Method of Operation of System

FREQUENCY OF PICKUP

LOADING PROCEDURES

SPREADING METHODS

STORAGE FACILITIES (TANKS, LAGOONS, ETC.)

5a. Type of Hauling Equipment

1. TYPE | CAPACITY
   LICENCE No. | P.C.V. No.
2. TYPE | CAPACITY
   LICENCE No. | P.C.V. No.
3. TYPE | CAPACITY
   LICENCE No. | P.C.V. No.

5b. Type of Spreading Equipment

TYPE

DESCRIPTION

6. Proposed Disposal Site

a SITE LOCATION (COUNTY, DISTRICT - TOWNSHIP)

CONCESSION No. LOT No.

OWNER - NAME

ADDRESS

TELEPHONE

b SITE LOCATION (COUNTY, DISTRICT - TOWNSHIP)

CONCESSION No. LOT No.

OWNER - NAME

ADDRESS

TELEPHONE

c SITE LOCATION (COUNTY, DISTRICT - TOWNSHIP)

CONCESSION No. LOT No.

OWNER - NAME

ADDRESS

TELEPHONE

d SITE LOCATION (COUNTY, DISTRICT - TOWNSHIP)

CONCESSION No. LOT No.

OWNER - NAME

ADDRESS

TELEPHONE

6. (cont.) Proposed Disposal Site

e SITE LOCATION (COUNTY, DISTRICT - TOWNSHIP)

CONCESSION No. LOT No.

OWNER - NAME

ADDRESS

TELEPHONE

7. Alternate Disposal Site

a SITE LOCATION (COUNTY, DISTRICT - TOWNSHIP)

CONCESSION No. LOT No.

OWNER - NAME

ADDRESS

TELEPHONE

b SITE LOCATION (COUNTY, DISTRICT - TOWNSHIP)

CONCESSION No. LOT No.

OWNER - NAME

ADDRESS

TELEPHONE

c SITE LOCATION (COUNTY, DISTRICT - TOWNSHIP)

CONCESSION No. LOT No.

OWNER - NAME

ADDRESS

TELEPHONE

8. Planned Travel Route

9. Emergency Procedures

10. Remarks

DATE

SIGNATURE OF APPLICANT

HEAD OFFICE COPY

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.P76
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Proceedings : sludge utilization and disposal seminar.

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